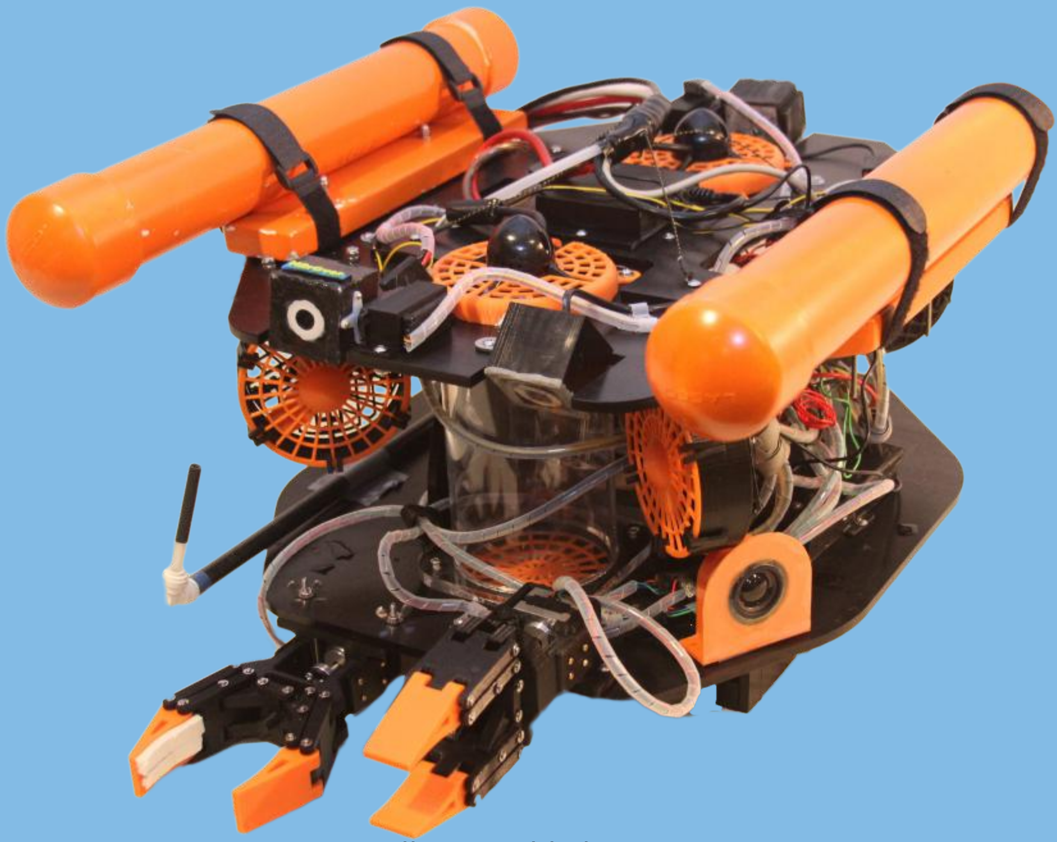
Curiodyssea

MATE ROV International Competition

Staples High School

Westport, Connecticut



Fully assembled H2rOver

Company Staff

Nicholas Durkin (11th)

Chief Executive Officer, Control/Electrical Engineer, Data Analyst

Tyler Edwards (10th)

Chief Information Officer, Electrical Systems Engineer, Mission Strategist

John McNab (11th)

Chief Financial Officer, Design Engineer, Mechanical Engineer, Co-Pilot

Nathan Wang (10th)

Chief Safety Officer, Visual Systems Engineer, Tether Manager

Daniel Westphal (11th)

Chief Compliance Officer, Chief Marketing Officer, Propulsion Systems Engineer, Pilot

Mentors: Mike Durkin, Andy McNab, and Chris Stratton

Table of Contents

Abstract

Curiodyssea constructed the H2rOver – Project Lionfish, its third generation remotely operated vehicle (ROV), to meet the RFP requirements put forth by the Applied Physics Laboratory at the University of Washington. The H2rOver is designed to be a versatile vehicle which can maneuver through the Pacific Northwest's waters and protect the well being of the marine environment.

The H2rOver is able to locate and retrieve the wreckage of vintage airplanes, install and recover ocean seismometers and implement tidal turbines and other instruments that will monitor the environment. H2rOver features a state of the art chassis and propulsion system, onshore guidance and control system, integrated multi-camera video system, and custom designed mission tools.

The H2rOver is equipped with six motors, four cameras, two manipulators, and specialized mission attachments. The chassis of the ROV is made from Delrin (polyoxymethylene plastic), which is sturdy, relatively light and can be laser cut. The control system of H2rOver is comprised of an onboard Arduino, custom control software developed in Processing (Java language), and a Logitech F310 gamepad.

Curiodyssea is a company committed to manufacturing cost-effective, compact, and efficient ROVs that are capable of operating in any type of marine environment and performing mission critical tasks for years to come.

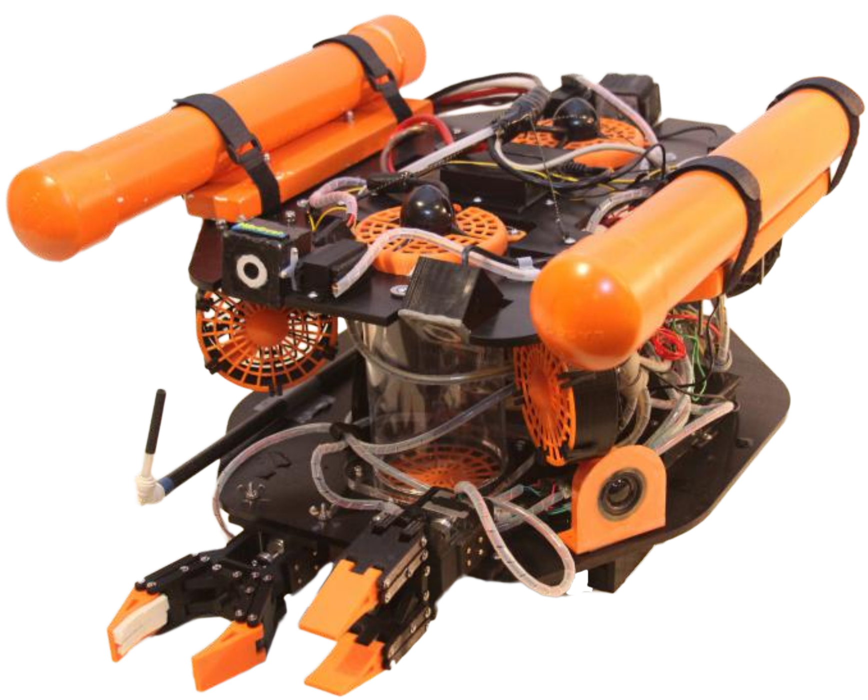
Underwater test of H2rOver

Technical and Scientific Concepts Behind the ROV

After a thorough review of the *Underwater Robotics* textbook, key ROV concepts were identified and evaluated: structure and materials, buoyancy and stability, movement, power systems, navigation and control, and payloads. After receiving the 2018 Jet City RFP, Curiodyssea assessed the components and systems necessary to build an ROV that could complete the RFP specified underwater missions. Based on this assessment, a company objective for the ROV was established: build a remotely operated vehicle which uses multiple subsystems (cameras, manipulators, etc.) to effectively and affordably accomplish underwater missions while adhering to the size and weight restrictions for the requested ROV.

Each member of the Curiodyssea team was assigned lead responsibility for one of the ROV’s core systems based on their expertise: Nicholas Durkin - electronics and control; Tyler Edwards - Ocean Bottom Seismometer (OBS); John McNab - chassis design; Nathan Wang - camera systems; Daniel Westphal - propulsion. The team then assessed the mission payloads and functionality necessary for completing underwater missions. All team members worked together to research and develop the mission specific systems (manipulators, speakers, etc.).

After creating a complete list of the required parts/systems, a model was designed in Solidworks (3D design software) to see how all the parts would connect. Prototypes of the ROV and attachments were virtually tested in Solidworks to identify possible issues and spatial requirements. This virtual testing of ROV concepts and systems saved time, money, and resources.



Fully assembled H2rOver - Project Lionfish

Budget Planning

After competing in multiple years of the MATE competition, we have a basic understanding of how much it costs to build an ROV. We budgeted spending $1,195, not including reused equipment and components, to cover our expenses. For fundraising, we had each family commit to contribute $250 to cover the budget for the regional competition.

Budget		
Section	**Cost**	**Components**
Tether	$75.00	Power wire, ethernet, serial cable, air hose, sheathing
Chassis	$400.00	Building material, machining, WTC
Motors	$100.00	Motors, PLA plastic for shrouds and mounts
Electronics	Reused + $220.00	Arduino, speed controllers, controler, wiring, Sensor
Manipulator	$60.00	PLA, motors, controllers
Cameras	Reused + $40.00	Baluns, cameras, monitors, mixer
Manipulator	$75.00	Stepper motors, PLA plastic, connecting pins
Attachments	$100.00	Lift bags, inflation hose, measurement device, ADV
OBS	$125.00	WTC, servo, arduino, acoustic sensor
ROV Subtotal	**$1,195.00**	
Registration	$150	Fee
Travel	$7,000	Travel, Lodging, Food
Subtotal	$7,150	
Total	$8,345.00	

Project Costing

By securing contributions, reusing old parts and carefully managing our expenditures, we managed to complete the project under budget. Our final ROV cost $1,100, excluding the value of reused/donated parts.

Project Costing

Reused		
Description	Year	Cost
T100s	2016	$300.00
Cameras	2016	$70.95
Camera Mixer	2016	$115.00
T-Shirts	2016	$150.00
Arduino Mega	2016	$28.49
Game controller	2016	$27.29
Fuse holders	2016	$16.99
Tools and Supplies	2016	$231.13
Computer Monitor	2017	$100.00
Total		$939.85

Donated		
Description	Source	Aproximate Cost
Delrin Laser Cutting	Select Plastics	$1,400.00
Total		$1,400.00

New Expenditures	
Description	Cost
Manipulators	$99.74
Watertight Case	$249.00
Servos	$34.47
Tether	$64.92
Motors and ESCs	$83.48
PLA plastic	$43.98
Topside Control	$63.74
OBS components	$79.15
Lift Bag	$63.20
Materials (Epoxy)	$131.79
Screws and other Misc	$187.33
ROV Total	**$1,100.80**

Travel and Other Expenditures	
Description	Cost
Transportation	$2,500.00
Food	$1,000.00
Registration	$125.00
Lodging	$3,400.00
Model Materials	$74.32
Total	$7,025.00

Project Total	$8,125.80

Design Rationale

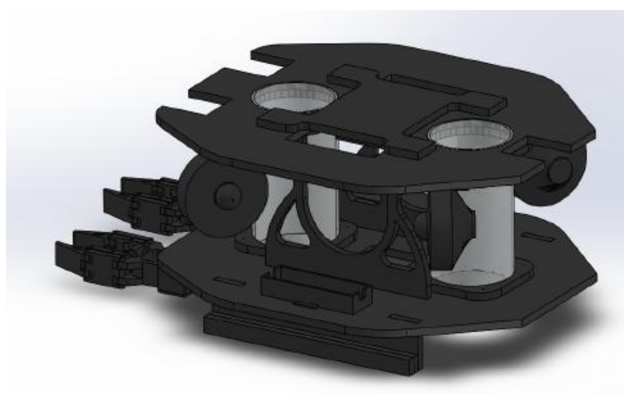
Curiodyssea's design rationale follows a system-based methodology. Our process is to divide the ROV into systems (electronics, chassis, vision, propulsion, attachments), and then divide those systems into components. Each component is designed, tested (in the workshop and in water), and integrated into the respective system. Then each complete system is tested independently, before incorporating all of them into the final ROV. This enables Curiodyssea to have confidence in the operation of all of our systems before assembly.

Developing an ROV with modular systems and components was a major focus of Curiodyssea's approach to design this year. The benefits of the modular design are the ability to take apart and reconstruct the ROV quickly and easily, allowing the company to update/repair certain components, isolate individual systems, and easily and safely transport the ROV. For example, the chassis is designed so that the electrical system can be completely removed in a few minutes of work so that updates and repairs can be done quickly and easily.

Based on the company's previous experience, several key systems were identified that needed to be improved:

- **Electrical system** - Improve wiring design and management for better reliability, ease of use, and accessibility to components.
- **Propulsion system** - Create custom-made thrusters to better fit the needs of the ROV. These thrusters are stronger, more efficient, and more reliable than previous designs.
- **Manipulator** - Develop a bigger, stronger, faster, and more versatile solution to meet the operational challenges of an underwater environment. We also added a second manipulator so we could execute simultaneous mission tasks.

Size and weight were important design considerations for the ROV. For size, the ROV is constructed to fit into the smallest size category to receive maximum points. For weight, we evaluated the choice between maximum weight points and the improved stability and navigation performance of a heavier ROV. In the end, we favored developing a more stable ROV that would make it easier to complete the underwater missions, to facilitate scoring more overall points in the competition.



Full ROV Design in Solidworks

Another important design consideration we faced was the evaluation of commercial vs. in-house developed components. When assessing these decisions we considered cost, availability, necessary customization, reliability, effectiveness and required expertise. Both commercial and in-house components had their respective advantages and disadvantages:

Cost - Many non-electrical components cost less to create in-house. Electrical components are cheaper to purchase.

Availability - Specific or customized attachments are often unavailable for purchase. Depending upon the component, the product may only be available overseas, costing valuable time to ship.

Customization - Pieces that require specific dimensions are often unavailable for purchase. Using a 3D printer is a good way to create customized attachments and mounts for specialized needs.

Reliability - Commercial components are typically more durable and reliable. As such, electrical components and motors are purchased.

Effectiveness - Electrical components are difficult to create from scratch, and much more effective when purchased.

Required Expertise - Certain components such as the steppers, electronics, and servos, required the knowledge or resources of an expert or manufacturer that we did not have in-house.

Chassis

The chassis was designed in Solidworks, a 3D design program used by engineers around the world. Designing the chassis using this software allowed us to test many different ROV designs and components without having to build physical models. Once the chassis design was finalized, the design files were exported to a professional plastic cutting shop which laser-cut precise parts for in house assembly. A cardboard version of the chassis was first laser cut which allowed us to make corrections before the final product was cut out of Delrin.

Cardboard chassis model

To optimize space on the ROV, Curiodyssea used an octagonal design with rounded corners to fit within the RFP's 60 cm sizing circle. The two “decks” in the chassis enable efficient positioning of system components, allowing us to line up cameras and attachments on the front and back, place motors on the diagonals where they can be vectorized, and set buoyancy on the outer edges of the ROV.


Assembled chassis without other systems installed

Delrin and acrylic were selected for the chassis materials because they are strong, relatively light, can be precisely cut, and are easily assembled. The chassis is comprised of two laser cut Delrin sheets, two Delrin braces for the watertight case, two acrylic vertical tubes, and Delrin skids. The vertical acrylic tubing creates structure and directs the flow of water from the T100s through the core of the chassis without interfering with other systems.

The modular chassis has seven distinct structural components and can easily be assembled using a system of bolts and interlocking tabs (tabs slide into designated slots). This allows the quick breakdown of the ROV for updates, repairs, and easy shipping.

Buoyancy and Stability


Foam and PVC for buoyancy

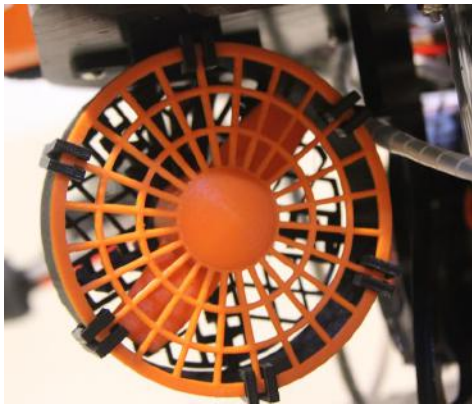
A neutrally buoyant, stable ROV is essential to complete missions, avoid drift when working on mission tasks, and have consistent navigational movement. To optimize the buoyancy and stability of H2rOver, the center of mass was lowered by putting weight on the bottom of the chassis and the center of buoyancy was raised by adding flotation on the chassis' top sides. There are many factors that influence the overall buoyancy of the ROV, but the most significant are the buoyant foam, air-filled PVC tubes, watertight case, and ballasts. We installed high-density foam along the upper sides of the ROV and added PVC tubes filled with air (which quickly attach to the ROV using velcro) in order to move the center of buoyancy upwards over the center of mass. Keeping these two points in line maximizes the overall stability. The high density foam and PVC tubes were chosen because they do not compress at lower depths. We were also able to lower the center of mass to further increase the stability by using adjustable ballasts attached to the ROV's skids. Because of the intentional placement of the center of buoyancy and the center of mass, the H2rOver is a very stable, neutrally buoyant ROV.


Adjustable ballast system on ROV

Propulsion

H2rOver utilizes two different types of thrusters: T100s for vertical movement and custom built brushless thrusters for horizontal movement.

The Blue Robotics T100s were reused from earlier ROVs because of their high thrust and reliability. The T100's, which draw up to 7 amps at our max power, are mounted in acrylic tubes that channel the thrust of the T100s through the chassis without obstruction. The front/back alignment of the T100s make it possible to pitch if necessary for missions.



Assembled thruster mounted on the ROV

Curiodyssea previously used bilge pump thrusters which were inefficient, slow, and the source of many power/reliability issues. The H2rOver now uses custom-built brushless thrusters for its horizontal movement.

While researching thrusters, we looked at both brushless and brushed motor solutions. We chose brushless motors because they were more powerful and easier to waterproof. We purchased several sets of motors to test and settled on the 750kv prop drive motors for their ease of waterproofing and accessible mounting points.

Brushless motor being waterproofed

To create the thrusters, we waterproofed the motor stators that contained exposed copper wires. This was done by surrounding each stator with packing tape and saran wrap and then filling the copper windings with epoxy. Once waterproofed, we designed a shroud, guard, and mount that could be 3D printed and snapped together. We designed, printed, and tested (with a bollard thrust test) a series of 3D printed propellers in order to determine which one fit the motor optimally.

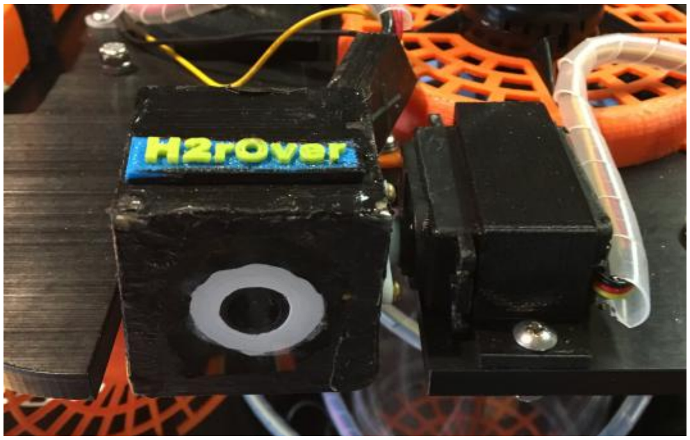
Components of the in-house thruster

The final thrusters contain 17 components and are completely 3D printed, except for the motor and screws. 3D printing gives us great flexibility in replacing and modifying parts, since the thruster parts are easy to produce. Each thruster produces 3.2 newtons of thrust and costs $21 for both the ESC and motor, including $2 worth of filament, forming a cheap yet powerful motor.

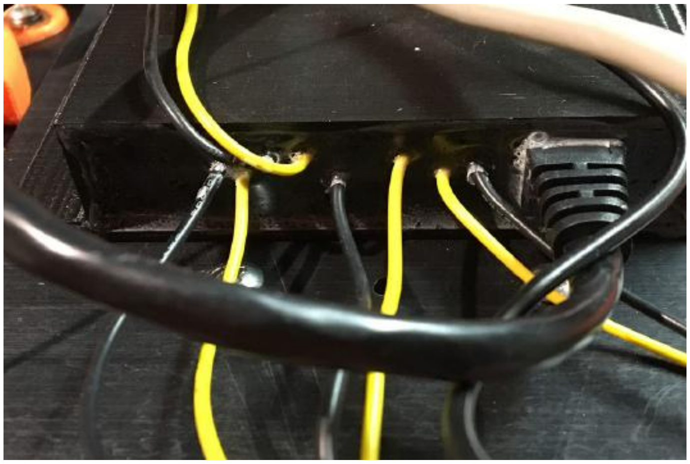
Camera System

Since visibility is essential to completing missions and a functional ROV, Curiodyssea's goal was to build a multi-camera system that provides effective sight lines for all missions and general navigation. In addition, the system had to be cost-effective, lightweight, and capable of viewing and managing multiple video feeds.

H2rOver is equipped with four 800TVL color board cameras that are waterproofed in custom designed, 3D printed cases using epoxy resin as a sealant. There are two cameras mounted in the front, one in the back, and one underneath the ROV to provide the vision fields necessary to complete all ROV operations. The primary front camera, back camera, and the bottom camera are mounted to waterproofed servos which adjust the camera view 180 degrees to dramatically increase the range of view from these camera positions.



Primary front camera mounted to a servo



Waterproofed balun and shielded Ethernet cable

H2rOver's video system uses a shielded Ethernet cable and two baluns to transfer video signals between the ROV and the poolside control station. One waterproofed balun is onboard the ROV and the other is located in the topside control system. Instead of utilizing BNC (Bayonet Neill–Concelman) connectors, the four cameras are hard-wired into the onboard balun to conserve space. The baluns enable the signal conversion of four video signals into one shielded ethernet cable which minimizes weight and makes the tether easier to manage. The shielded ethernet cable was selected to minimize electrical interference from the power cables, which can impact the quality of the video signals transferred via the tether.

To manage the multiple video feeds, the control station has a high-quality video mixer with a color quad processor that enables the simultaneous viewing of four cameras on one monitor without signal delay, as well as offering multiple viewing options for the pilots.

Electrical/Control System

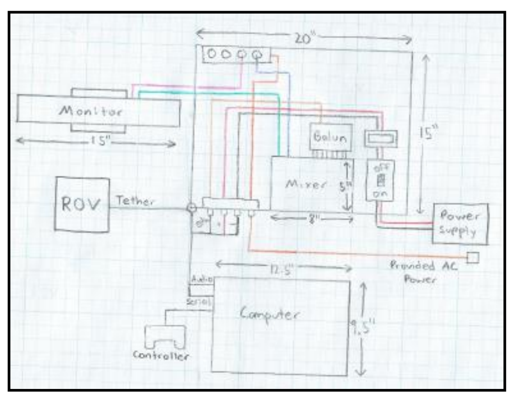
The control system's purpose is to manage all of the electrical components on the ROV and give the pilot and co-pilot the ability to intuitively operate the vehicle. The system controls all of the motors, steppers, and servos through an onboard Arduino Mega, which communicates with the topside controller to exchange information about motor power and sensor information. The system is designed to give easy access to components for troubleshooting or updating: all wiring connections are detachable, the watertight case is accessible, and the Arduino is easily reprogrammable.

Improving electrical connections outside the watertight case was a priority this year. Through extensive testing, we learned that water can penetrate the ROV's watertight case through minuscule openings in the wire casing. To correct this potential problem, splices in the wiring are minimized and connections are made within epoxy boxes (3D printed cases that fit around the wires and are filled with marine epoxy) for a robust watertight seal.

Sealing an epoxy box

One of the important innovations in the control program was the implementation of packet-based control signals. We noticed that Curiodyssea ROVs occasionally received incorrect power values over the serial cable and caused motors to temporarily fail. To fix this, we implemented self-hashing features to the signal data packets allowing the ROV to confirm the power values matched an attached checksum value, dramatically decreasing the possibility of exchanging bad signals between the ROV and control station.

Topside Control Station - The topside control station is composed of three main parts: the monitor (which displays the views from the ROV's cameras), the computer (running topside controls and communicating with the onboard Arduino), and the control box (which houses several control features for pilot use, including a master power switch, video mixer, power monitor, and topside balun).



Mechanical drawing of topside control system

The topside control station is designed to be operated by two pilots. The main pilot operates a Logitech F310 Gamepad which steers the ROV via the six directional thrusters. The Gamepad is connected to a laptop, which runs a Processing (a Java-based program) sketch which communicates with the Arduino to send motor and sensor data. The co-pilot operates an intuitive user interface which allows adjustment of the camera or manipulator positions from the computer.

Watertight Case - The onboard electrical components are contained in the watertight case and organized on a 3D printed rack, which keeps the components secured in place and accessible. The wires are strategically organized within the case so that all of the connections fit into position on one end cap of the case. The opposite end cap can be quickly removed to provide access to the Arduino's USB connector for software updates (this is a major time saver when updates are required).

Watertight case

The watertight case also contains a water sensor, located on the bottom of the case to give an early warning alert in the event of a leak. Upon detecting any water, the Arduino notifies the pilots, who then quickly return the ROV to the surface to ensure operation is safe, the components are not harmed, and address the leak.

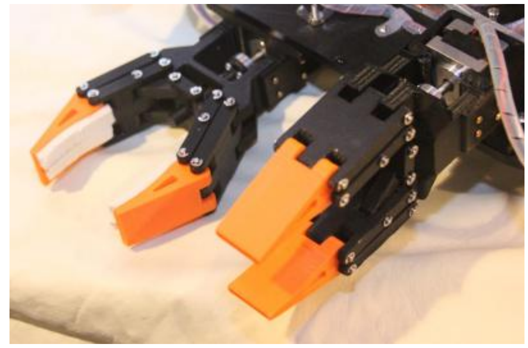
Tether - The tether provides all necessary connections from the topside control station to the ROV. The tether contains two 8 gauge wires for power supply, an RS232 serial cable for data communication, a shielded ethernet cable for the video signals, an audio cable to control the speakers, and a ¼" polyethylene tube to inflate the lift bag. All components are at least 15.25 meters long to reach to all areas of the mission field. The tether is braided and wrapped with velcro ties to keep it neat and manageable, without adding weight. The tether terminates on the ROV with a strain relief system made from four kevlar strings which center the tether on the top of the ROV. The "Mega Claw," an expandable clip, is used to keep the tether neatly coiled during transportation and storage.

The braided tether with foam flotation and mega claw

The tether is carefully engineered to be neutrally buoyant, which minimizes tether drag while navigating H2rOver, making it easier to control and complete missions.

Manipulators

One of Curiodyssea's goals was to improve H2rOver's manipulators. Compared to previous designs, the manipulators needed to be bigger, stronger, and faster to complete the required underwater missions. Curiodyssea designed the manipulators from the ground up using stepper motors instead of servos and replacing smaller 3D printed pieces with fewer, larger 3D printed pieces. These modifications have strengthened the claws of the manipulator to keep it from breaking under stress during missions.



Manipulators mounted on the front of the ROV

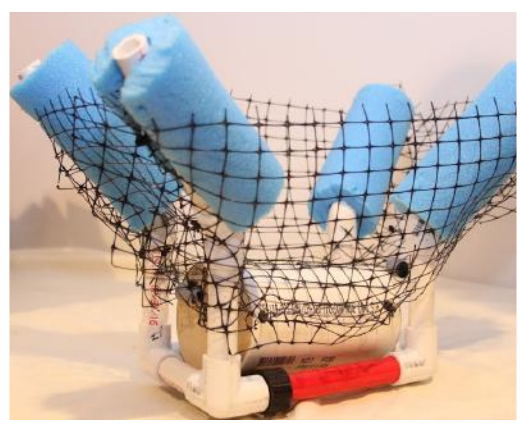
The ROV has two manipulators so that it can grab multiple objects, making it possible to complete more missions in a shorter period of time. One manipulator is mounted in a horizontal position and the other is mounted in a vertical position so the appropriate one may be used for each respective mission.

Ocean Bottom Seismometer (OBS)

The OBS combines an acoustic sensor system, frame/basket, and locking mechanism.

The acoustic sensor is a Sparkfun electret microphone used to read sound data to an Arduino Uno. We looked at several algorithms for sound detection and after extensive research and development concluded that pitch was the best measurement to use by recognizing the presence of certain frequencies. The sensor is waterproofed in a film canister filled with air. It detects tones from the ROV's two onboard waterproof speakers.

The OBS frame is comprised of interconnected PVC pipes. The bottom is weighed down with ballast and the top has flotation foam, creating a stable OBS. The connector is transported to the surface via a mesh basket which is lightweight and large enough to easily store the connector. At the center of the frame is the OBS watertight case where all of the control electronics are held. The case is designed to be easily accessible for updates and repairs.



The OBS

The OBS's locking mechanism, located at the bottom of the frame, is comprised of a servo with a custom 3D printed horn and an additional 3D printed piece to prevent a string from slipping out of the lock until activated.

Lift Bag

Curiodyssea conducted extensive research and testing to learn about lift bag use before selecting the lift bag that would best suit the needs of the mission.

The factors we considered included: number of lift bags, material and shape, attachment mechanisms, inflation methods, inflation times, and tether tubing options (different sizes and materials). We considered polyethylene, nylon ripstop, spinnaker cloth, and vinyl coated nylon. These were all tested in a pool in order to determine which performed best. Material testing revealed that the polyethylene lift bag was difficult to work with and modify for the mission and the rip stock and the spinnaker cloth both lift bag had air escaping through the seams which could not be sealed. We ultimately chose a commercial lift bag because it has a valve, is airtight, and has a large lift capacity.

The selected lift bag is a commercial, vinyl coated nylon bag. It is capable of lifting 25 pounds when fully inflated. It has been extensively customized with:

- Large 3D printed hook that can be easily attached to the debris and engine
- Tennis balls inside the lift bag provide a small upwards force, ensuring that the bag stays upright at all times during deployment
- Modified air release valve to reduce the force needed to open the valve and deflate the bag
- PVC ring installed in bag’s bottom opening to facilitate insertion of the air tube

In order to inflate the lift bag, we tested tubes with different sizes and materials to see what would be optimal. Polyethylene tubes with larger diameters and rubber tubes were inflexible and limited ROV movement whereas tubes with small diameters were difficult to pump air through. The optimal solution for inflating the lift bag proved to be a ¼” polyethylene tube since it provided the desired flexibility while also filling up the lift bag relatively quickly.

Lift bag prototypes. Final bag is on right.

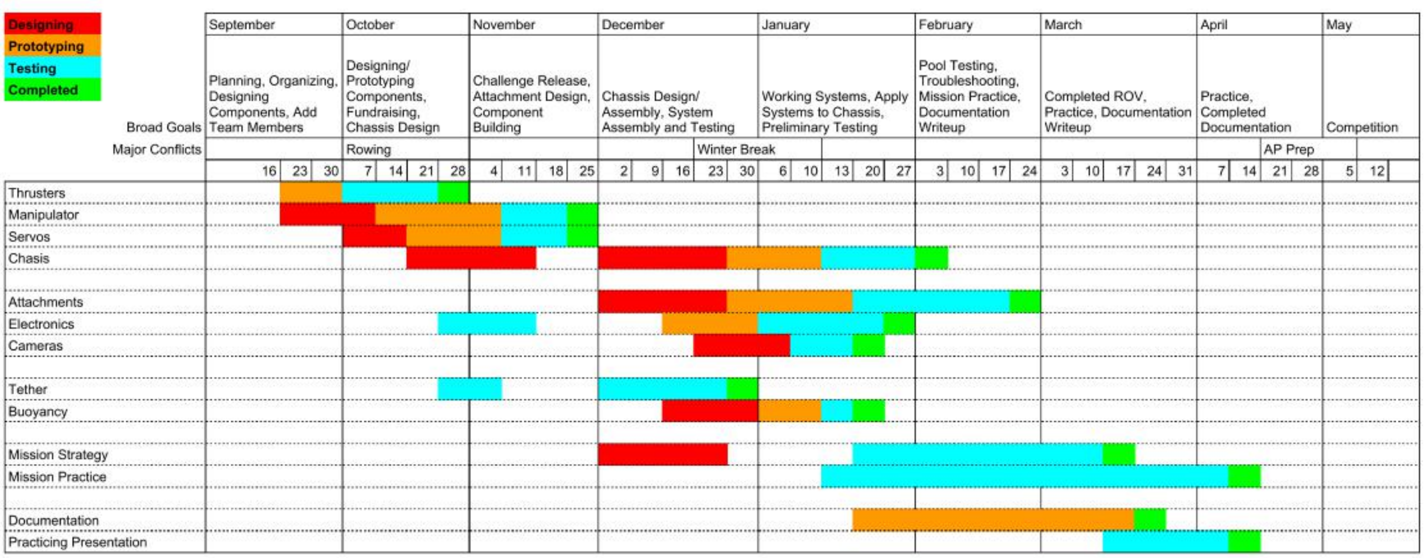
The air tube is mounted on the right side of the ROV in the front so that it is visible to the cameras and can be moved underneath the lift bag without interfering with other parts of the ROV. An elbow valve is installed on the end of the tube in order to vertically pump air into the lift bag.

Project Management

Another important improvement that Curiodyssea made was to create a detailed schedule to ensure that there was plenty of practice time before the competition. In order to get a head start and stay ahead of schedule, Curiodyssea began to plan prior to the release of the 2018 RFP. We knew that certain systems needed to be upgraded (see Design Rationale), so we focused on finding solutions for these systems. We divided work assignments on the ROV to have system leaders who specialized in each area of the ROV's development (electronics and control, chassis, propulsion, cameras, and propulsion). Each project leader adhered to the Gantt chart, which ensured that development proceeded on time. It also allowed each project leader to focus on their respective system and become our in-house expert in that area. The deep insights gained by the project leaders meshed to increase the extent of our knowledge and made the overall team much stronger when developing of the ROV.

Emails and texts were the primary means of communication. Notices were sent to all members of the team in order to keep everyone updated with meeting schedules. Additionally, these communications contained a small recap of what occurred at each meeting as well as an outline of our short-term goals.

Every time we met we had a recap and planning session to review what we did last session (in case someone missed the previous meeting) and to plan what had to be accomplished that session. During this time, members also were able to ask for assistance and help on assignments. Additionally, at the end of every meeting, we compiled a shopping list that would specify exactly which parts needed to be purchased for the next session to be as productive as possible. This year, we began keeping an inventory to track all of the materials we had available to us so that we could easily tell when we needed to replenish supplies.



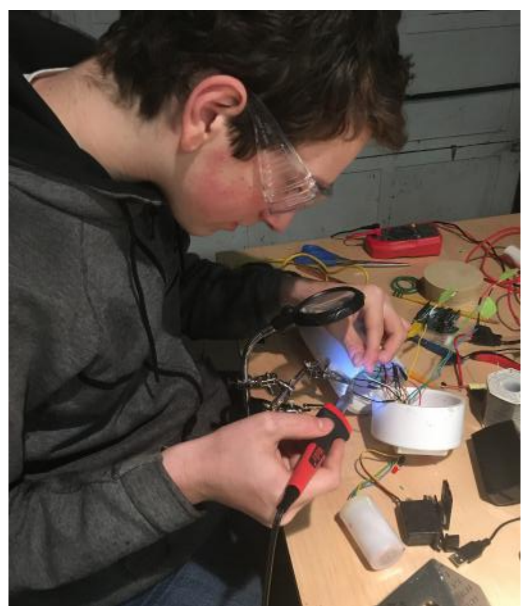
Company schedule

Safety

Safety is very important to Curiodyssea and our philosophy is to make sure that every aspect of building and operating our ROV is safe. We identified and implemented safety features and measures in three separate areas: on the ROV, in our workshop, and while testing in the pool to keep all members safe. These measures are outlined in our safety checklists (see next page).

Caution signs installed on the motors

The most hazardous parts of the ROV are the electrical system and the motors. Curiodyssea wanted to ensure that these parts would not cause any injuries during the building and operation of the ROV. We developed a series of safety protocols that were followed at all times. Curiodyssea implemented the required 25 amp fuse into the electrical system before testing any components. This, along with a master switch that could instantly cut power to the ROV, minimized potential power hazards. For motor safety, we built custom shrouds that covered all sides and made sure motors were always securely mounted before running, checked for any wire entanglement, and required verbal confirmation between members before starting the motor operation. In addition, caution signs were installed on motors to warn of dangerous areas on the ROV.



Curiodyssea member carefully solders wires together

Another important part of safety was waterproofing electrical components. Major connections were waterproofed with 3D printed cases filled with silicone, marine grease, or epoxy. These include the power distribution boxes, the balun, the RS232 converter, and the cameras. Wire splices were sealed with “epoxy boxes”, 3D printed cases designed to fit around the electrical connections and be filled with epoxy. The watertight case was used to seal the main electrical controls within the ROV. This includes the Arduino, ESCs, and the 5 volt converter.

In addition to our workshop protocols, we also have a logbook to list safety incidents to help us track and analyze any problems. We are proud to say that we have been incident free for two years because of our respect for and implementation of the safety protocols.

Curiodyssea Safety Checklists

ROV Safety Features:

____ Tether strain relief

____ Shrouded and guarded motors

____ Color coded wires

____ Installed fuses

____ Safe and waterproofed wire connections

____ Caution signs installed on motors

____ Rounded and dull edges

Workshop Safety Measures:

____ Closed toe shoes while in workshop

____ Safety glasses when in the workshop

____ Mentor supervision when in workshop

____ Safety guards for soldering iron to prevent burning

____ Using gloves when handling hot materials

____ Covering all open wires when conducting electrical tests

____ Tracking all safety injuries and making improvements to safety procedures to prevent additional injuries

____ Maintaining a clean work environment when in the workshop

____ No loose clothing when in the workshop

Poolside Safety Measures:

____ Wearing closed toe shoes and safety glasses

____ Installed 25 amp fuse

____ Tether strain relief in place

____ All tether wires properly and securely connected

____ Anderson Power Poles plugged in properly (red is + and black is -)

____ Switches in the off position

____ On-shore components secure

____ All moving parts are secured and clear of possible hazards

____ Verbally confirmed everyone is ready for operating the ROV

Testing and Troubleshooting Techniques

We used the scientific method, the process for scientifically testing a hypothesis, and independent variable testing to identify and fix issues encountered while designing, constructing, and troubleshooting the ROV.

An example of this process is illustrated through our waterproofing of wires.

For the last two years, our watertight case has leaked. We could not locate the source of the problem and we wanted to ensure an entirely dry case this year. We implemented a series of tests to identify the issue and concluded that the water was entering inside the insulation of the wires through non-perfect seals. To confirm this observation, we enclosed all of the case's wires in epoxy and then left the case in a pool for two hours; it was found completely dry, meaning that we had isolated the issue.

3D printed prototypes

Another way we troubleshot was prototyping and testing all of the systems and attachments thoroughly in the workshop before pool testing. The components were easier to replace or fix prior to being waterproofed, and we were able to identify issues before incorporating the system into the final ROV. We tested the cameras' fields of vision, what the manipulator would be able to handle, specialty attachments, control of the electrical system, and anything else that had a chance to fail. This testing process minimized any errors prior to final assembly of the ROV. The final testing of the completely assembled ROV was done in stages. We first dry tested all installed systems in the workshop, and then began pool testing. Pool testing was done by submerging the ROV for increasing time intervals until we were confident all components were waterproof and working. We then moved on to basic navigation, and then mission trials.

We encountered difficulties arranging pool time to test the ROV. We asked our school for pool time and were given some time to work on the weekends. However, the time was not sufficient for our rigorous testing program. We also contacted the local YMCA and were able to use their pool for a limited amount of time. We used both of these resources to their fullest extent until one of our teammates opened up their pool, allowing us to test our ROV more intensely.

Electrical system troubleshooting

Future Improvements

Project Management - One future improvement that we would like to make is getting testing time earlier in the season. We began working on our ROV and mission-necessary parts as soon as the RFP was released, however, we did not begin testing different components until late February. When we tested our parts we learned that our theoretical calculations and reasoning were quite different from what actually happened. It was a challenge to troubleshoot and replace different parts and attachments needed for missions in order to get an entire ROV operational by the end of March. If we had testing time earlier in the year, we would have been able to fix these issues earlier and have more practice time.

Design Process - Another future improvement would be to have a better schematic for wiring. We made sure that all the wires inside the watertight case were neatly organized, however, the wires outside of the case were not planned out well. The wires were soldered together before attaching all components to the ROV, resulting in the tangling of many of the outside wires. We eventually redid some of the connections to better organize the wires. If we had planned out the wiring concept before implementing it, the wiring system would have been more organized and less time would have been spent cutting and re-soldering connections.

Challenges

Non-technical - The most prominent organizational challenge that we encountered this year was being able to get our team together to work on the ROV. We all had sports or other extracurriculars in addition to our school work, which created conflicting schedules for meeting times. In order to remedy this issue, we decided that we would have meetings on Saturdays and Sundays and that people would come whenever they could and work on their designated system. It was also decided that there would be meetings over April break so that we could all work together to put together our systems and conduct tests on the ROV.

Technical - The biggest technical challenge that we faced was getting the stepper motors to work correctly on the manipulators. Initially, there were three stepper motors on the ROV: two for opening/closing the manipulators and one that acted as a wrist on the right manipulator. The rotor of the stepper that controlled the wrist was put under too much stress to function and therefore did not work. We evaluated several solutions to the problem, including a gearbox to reduce the stress on the rotating axle, but determined the ROV would still have full functionality with two stationary manipulators, one mounted horizontally and one mounted vertically. In addition, the stepper motors kept overheating due to their constant use throughout the missions. Therefore, a program was implemented that would automatically turn off the stepper motors when not in use.

Lessons Learned

Interpersonal - This year Curiodyssea added a new member to the team, Tyler. We taught him about the basic functionalities of an underwater ROV and slowly introduced him to the "ROV world." Then he was assigned the development of the OBS system. The team learned how to integrate new members into an existing group through this experience. We learned that in order to best introduce someone to the team, they first need to be taught the basic skills and concepts and then assigned to a specific task (and, of course, provided with assistance as needed until they are autonomous). This will be very useful next year as we aim to add more new members.

Technical - This year we developed a new way to waterproof all our connections on the ROV by building waterproof casings for each connection. Since standard soldered connections covered in heat shrink proved ineffective and lead to leaks, we knew that we had to come up with another solution. Using Solidworks and Google SketchUp, we created custom cases that encased the soldered wires and were then filled with epoxy. After much testing, we learned that this was the most effective way of waterproofing our wires, a major problem in previous years.

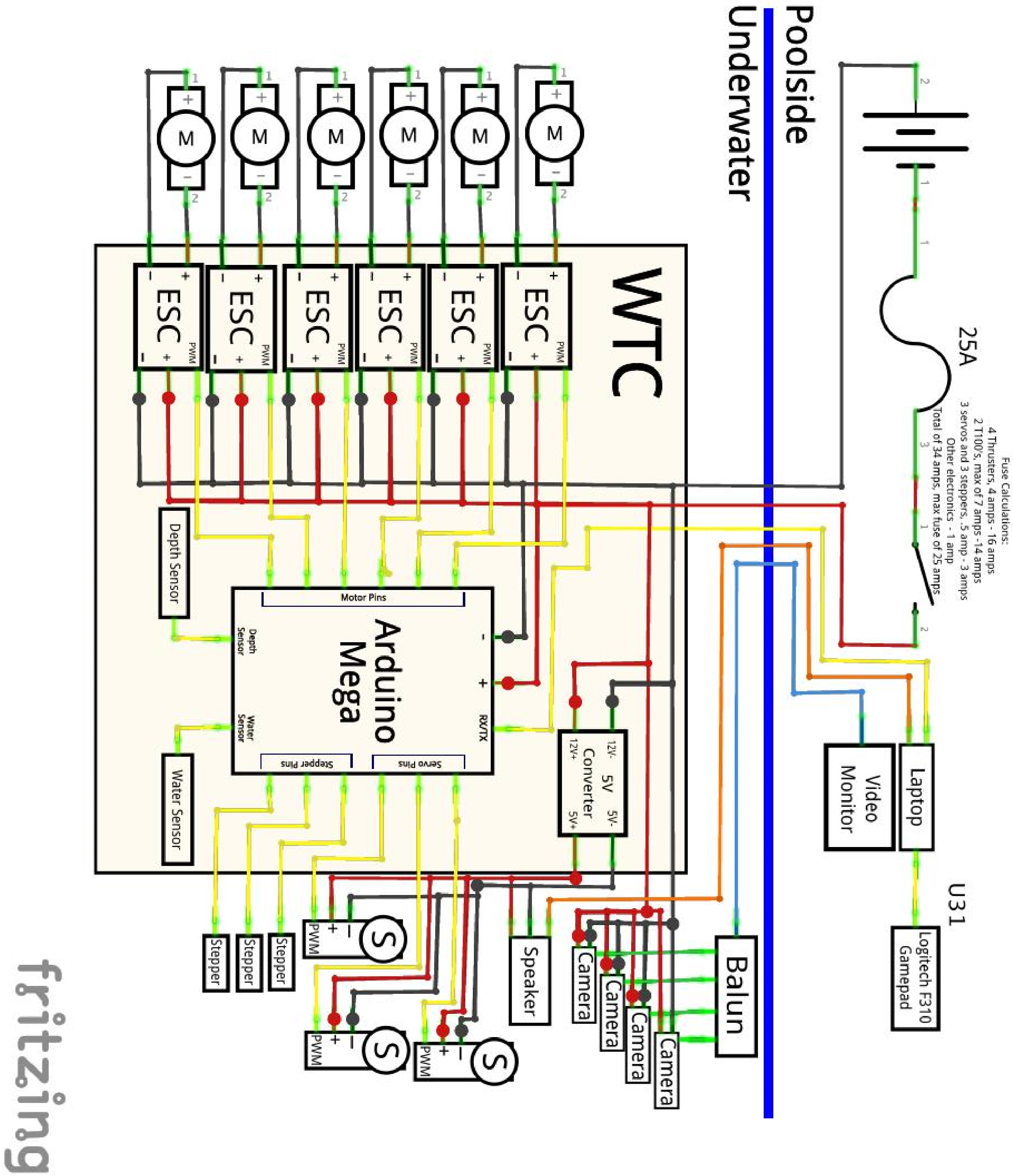
Another technical lesson skill we learned was the process of annealing plastic. Last year's ROV, made entirely from acrylic, cracked in multiple locations. We researched this issue and learned that acrylic is susceptible to cracking when laser cut because the plastic molecules become misaligned. We corrected this situation with the acrylic parts by annealing them prior to assembly. To anneal acrylic, it is heated to 170 degrees Fahrenheit for eight hours. This aligns the molecules and makes the acrylic more structurally stable, therefore lessening the chance of it cracking.

Outreach

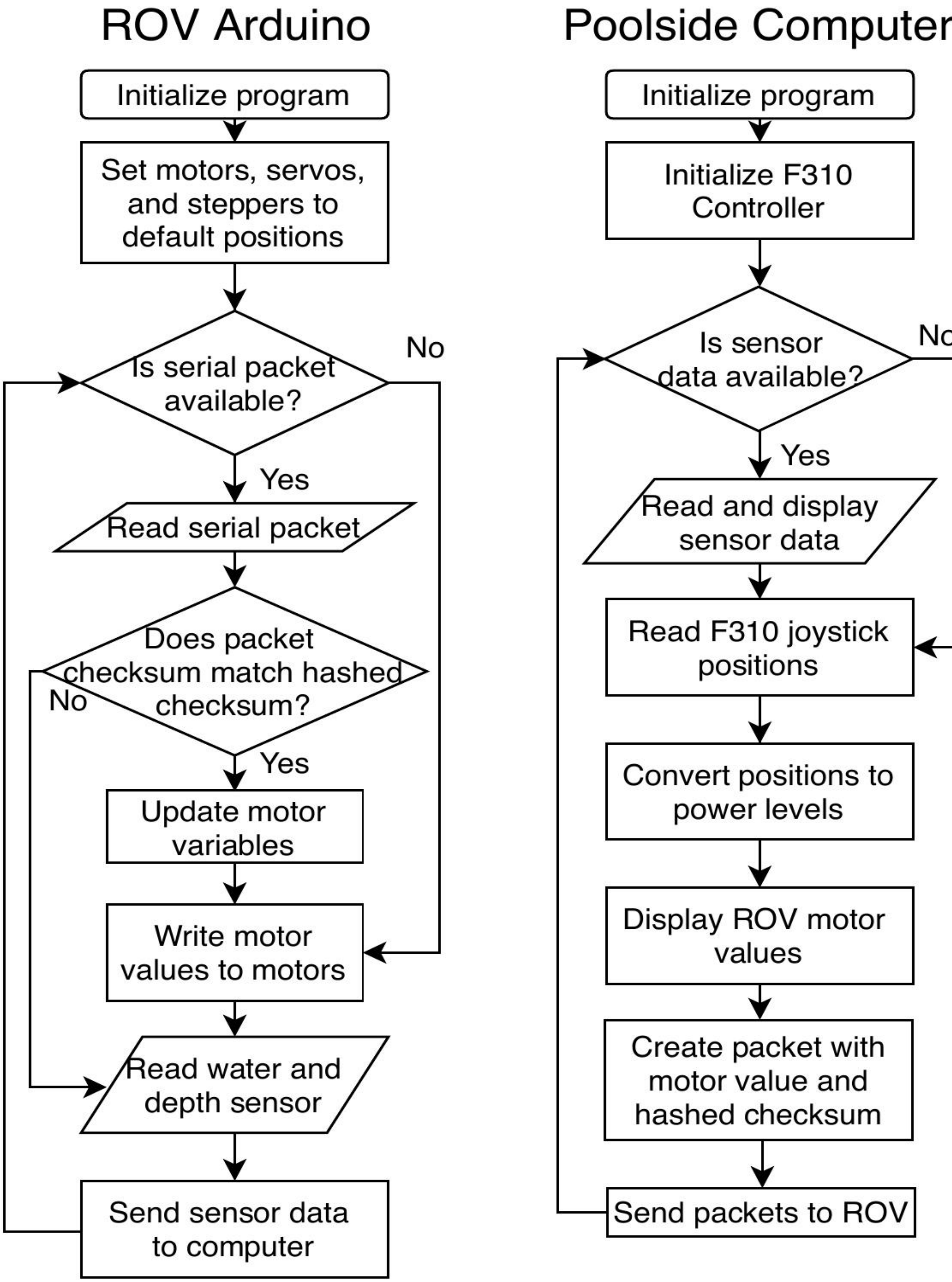
For community outreach, Curiodyssea exhibited our ROV at Westport's Maker Faire, an annual event showcasing many different "makers" and their hobbies, passions, projects. At this event, the MATE organization and the ROV were shown off to over 10,000 people from around the tristate area. We talked about the MATE competition, ROV construction, and marine engineering with students, teachers, manufacturers, and parents. This is Curiodyssea's second year participating in our town's Maker Faire, and we hope to continue participating in the years to come.

Curiodyssea at the Maker Faire

Systems Integrated Design (SID)



Software Flow Charts



References and Acknowledgments

References

Afro ESC USB Programming Tool – Instructions: FlyingTech. Web. 1 Apr. 2018

Arduino. "Arduino Forum - Index." Arduino Forum - Index. Arduino, 2016. Web. 19 Apr.2018.

Arduino. "Arduino" Arduino. Arduino, 2016. Web. 1 Jan. 2018.

Blue Robotics. "Blue Robotics - Marine Components, Parts, & Supplies." Blue Robotics. Blue Robotics, 2016. Web. 19 Apr. 2018.

Gammon, Nick. "How to Process Incoming Serial Data without Blocking." Gammon Forum. Gammon, 12 Nov. 2011. Web. 10 Apr. 2018.

Homebuilt ROVs. "Homebuilt ROVs Forums." Homebuilt ROVs Forums. Homebuilt ROVs, 2016. Web. 19 Apr. 2018.

Jordi. “Andromina Robot V.2.0.” AndrominaRobot, Andromina, 3 Aug. 2017. Web. 18 Sept. 2017.

Kajnjaps. "How to Build a Thruster for a Homemade Submersible or ROV." Instructables.com. Instructables, 2014. Web. 27 Jan. 2018.

MATE. "MATE- Marine Advanced Technology Education :: Home." MATE- Marine Advanced Technology Education : Home. Marine Advanced Technology Education, 2012. Web. 12 Nov. 2017.

Moore, Steven W., Harry Bohm, and Vickie Jensen. Underwater Robotics: Science, Design & Fabrication. Monterey, CA: Marine Advanced Technology Education (MATE) Center, 2010. Print. 6 Feb. 2018

OpenROV. "OpenROV Forums." OpenROV Forums. OpenROV, 2017. Web. 19 Apr. 2018.

Sopwith, Nick. “Thrusters - ROV Project.” ROV Project, 12 Aug. 2015. Web. 1 Jan. 2018

Acknowledgements

We would like to thank the following for their generosity in assisting our project:

Mentors - Mike Durkin, Andy McNab, and Chris Stratton

Westport Weston Family YMCA and Staples High School - Pool services

Select Plastics (Tony D’Andrea) - Chassis material and laser cutting

Nick Orndorff - Brushless thruster design assistance

Solidworks - License for Solidworks

Fritzing - CAD software for SID diagram

MATE - The MATE program

For questions, comments, or feedback, please contact us at Curiodyssea@gmail.com