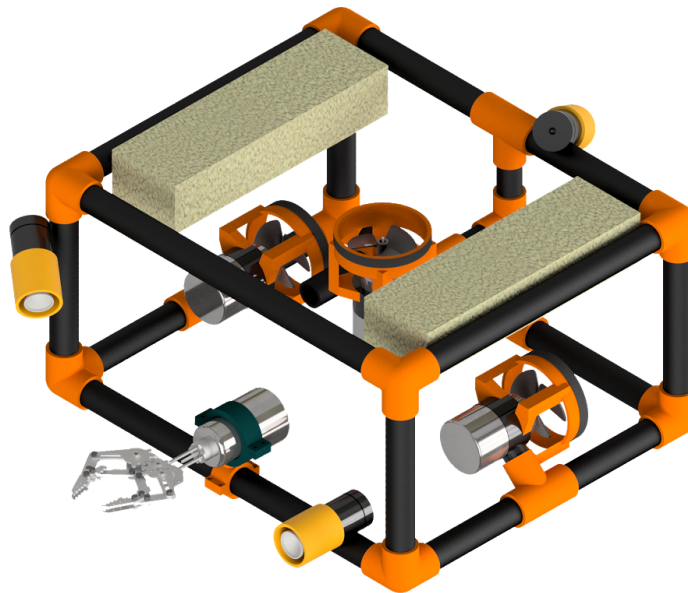
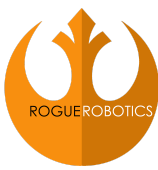


**2017 HACKADAY
PRIZE**
Technical Documentation



Volturnus concept model

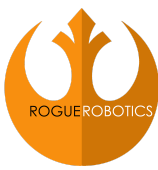
Background - About Us

Rogue Robotics, a team of high school students, designed and manufactured the *Volturnus* ROV, an underwater robot designed for low-cost pollution control. *Volturnus* is equipped with technology for both sensing and handling a wide class of aquatic pollutants. The simple, robust design is targeted toward ease of fabrication to easily enable home enthusiasts to modify and improve the ROV. We believe that opening up pollutant detecting technology to as many people as possible is the key to improving marine conditions in today's world.

We are Rogue Robotics, a team of high school students from all around central New Jersey. Seeing the dwindling supplies of accessible freshwater, we decided to combine our shared interest in robotics with a desire to improve the world around us and created the *Volturnus* ROV. *Volturnus* is an underwater robot designed for low-cost pollution control. It is equipped with technology for both sensing and handling a wide class of aquatic pollutants. The simple, robust design is targeted toward ease of fabrication to easily enable home enthusiasts to modify and improve the ROV. We believe that opening up pollutant detecting technology to as many people as possible is the key to improving marine conditions in today's world.

Problem Statement

While water is all around us in the form of oceans, lakes and rivers, only 2.5 percent of it is freshwater. Furthermore, only 1 percent of that freshwater is accessible, the rest being trapped in glaciers and ice caps. This small amount of water has the huge responsibility of meeting the needs of all living creatures on the planet. With freshwater supply quickly diminishing, it's more important than ever to ensure that the water that we do have is pure, clean, and available for



human use. Clean water also affects many animals, whether they drink the water itself or live in it as a habitat. Identifying bodies of water that are polluted is an area of great importance as we go forward in securing our world's water sources.

Remotely Operated Vehicles (ROVs) are the perfect robotic applications to detect marine pollution in hard-to-reach places in bodies of water. ROVs extend the capability of human divers and allow us to detect pollution and concentrate efforts where they're needed. However, existing ROVs are either expensive, multi-million dollar scientific systems designed for deep sea navigation or cheap, inefficient systems that are ill-adapted for targeted pollutant detection. A lot of people would agree that underwater pollutants are a huge problem, but the state of current technology puts practical ROV systems that can tackle these problems out of reach for communities that need it the most.

Links:

<https://github.com/allai5/volturnus-rov>
<https://roguebotics.weebly.com/>
<https://www.youtube.com/watch?v=UMHDCI13dYc>
<https://skfb.ly/69ysR>

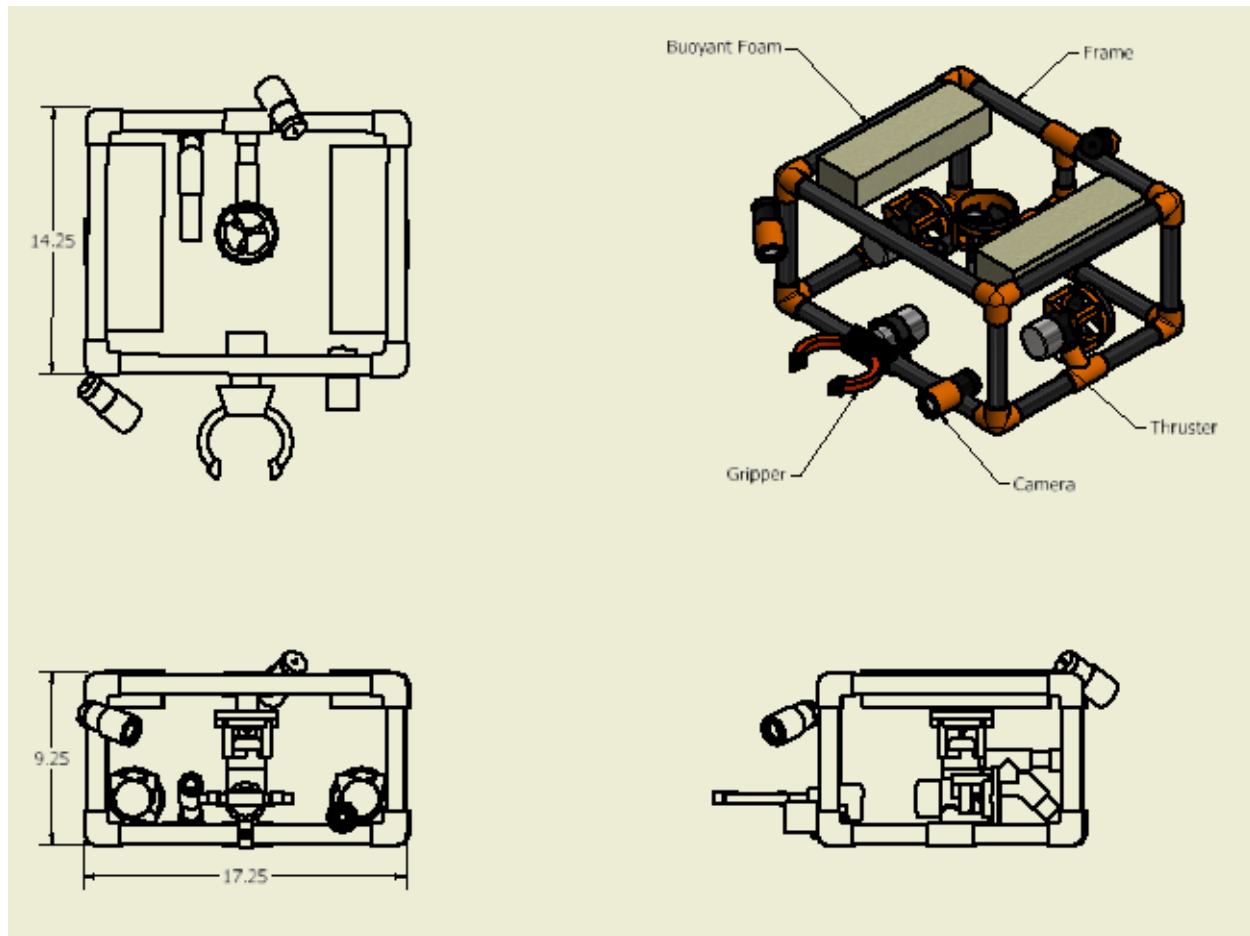
Our water is running out. While water is all around us in the form of oceans, lakes and rivers, only 2.5 percent of it is freshwater. Furthermore, the majority of that freshwater is trapped in glaciers and icecaps - leaving .025 percent of the world's water accessible to us for myriad tasks. This water is not only used for drinking, but for showering, sewage, cleaning, etc. When we are already under such water stress, losing water to pollution is unacceptable.

Objective

Rogue Robotics is starting a worldwide crowdsourcing campaign in utilizing low-cost, self-assembled ROVs to detect underwater pollution in local communities.

The World-Changing Underwater Robot

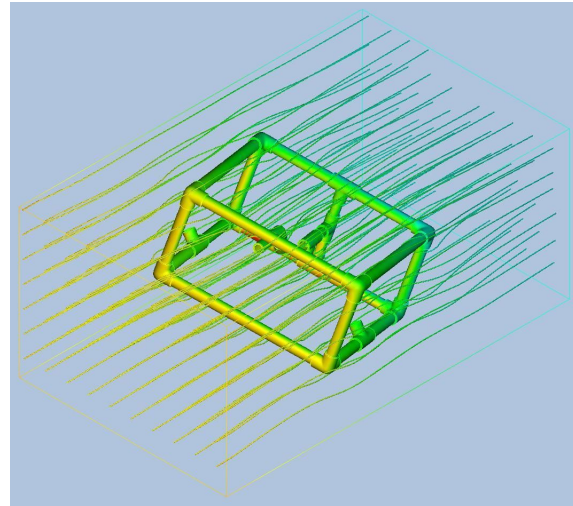
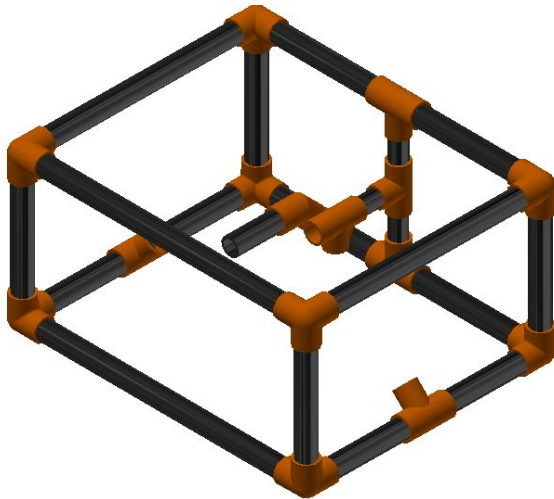
There are a few other low-cost ROV systems available for use, but *Volturnus* has a unique focus on underwater pollution and implementing cheap ways to detect it. *Volturnus* is designed with a philosophy of minimalism: *Volturnus* implements a few features but implements them well. Thus, *Volturnus* has the benefits of expensive ROVs, but also remains affordable. Not only does this result in an effective, uncluttered design, but it allows for users around the world to easily construct and modify their own devices. *Volturnus* may not be perfectly adapted to every single aquatic situation around the world, but by opening up the technology to any many people as possible, *Volturnus* has the potential to spark similar innovations across the globe.



Mechanics

Frame

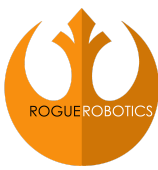
Volturnus's frame is made from PVC for maximum extensibility. PVC is a cheap, lightweight, durable, and water resistant material. A variety of connectors exists for PVC piping, so we can easily manipulate the size and shape of our frame. The affordability and accessibility of PVC are valuable qualities that support our mission of opening pollutant detection technology to as many people as possible.



The frame is designed as a “wet frame” to maintain approximately neutral buoyancy, which offers the best energy efficiency during driving. Neutral buoyancy is accomplished by drilling holes on the frame to allow water to enter and exit. The holes are 3/8th inch in diameter, big enough to allow the water to easily flow through while small enough to not ruin the aesthetics and not damage the stability of the frame. The drilled holes are spread out on the frame to ensure the weight of water is evenly distributed throughout the frame. Filling the PVC piping with water is an easier method of maintaining stability than making the structure watertight and balancing the air with heavy weights. Creating holes has the additional benefit of hiding *Volturnus*’s cables by running them through the frame. Hiding the cables improves the aesthetics of the ROV and also serves a practical purpose by effectively organizing the cables so that they would not get in the way of the propellers.

1. We began by researching various material types that can be used for the frame. Finding the best material requires finding an appropriate balance between performance and cost, as our goal is to develop an efficient apparatus accessible to the public. We summarized our research into a decision matrix.

Table 1. Decision matrix for frame material selection						
Material	Neutral Buoyancy	Strength	Weight	Price	Ease of Use	Total
PVC	4	3	4	5	5	21
HDPE	4	4	5	3	4	20
ABS Plastic	4	4	5	3	3	19
Aluminum	1	5	3	2	2	13



2. After deciding on using PVC piping, we discussed the ideal frame shape and size. We wanted to keep dimensions and weight to a minimum, as a smaller vehicle maneuvers more easily through water. We also placed a high emphasis on simplicity because simple designs are easier to develop and troubleshoot. The mechanics team sketched the frame layout on graph paper, including locations of thrusters, cameras, and tether attachments. We ultimately decided on a simple four motor orthogonal structure that maximizes space within the frame.
3. We then created a CAD model of our proposed frame in Autodesk Inventor. Creating a CAD model prior to construction allows us to visualize the design and confirm the idea is achievable. We first created individual Inventor parts, including 90 degree elbows, tee connectors, and PVC pipes of specific dimensions. We assembled the parts together based off of sketches, making sure to leave space for the gap between PVC pipes in connectors. Final dimensions did not exceed 12" x 12" x 18".
4. When we completed the CAD model, we created a list of parts to purchase for actual construction, including part name, quantity, and size. All PVC piping had 0.5" interior diameter to ensure consistency.
5. After purchasing necessary components from Lowe's, we worked on frame assembly. We marked a 10 ft. long PVC pipe with the appropriate dimensions and used a dremel to cut along our markings and smooth out the surfaces of uneven cuts. We joined the parts according to the CAD model, with elbow connectors to form corners and tee connectors to mount motors and cameras. Once we were sure that we could assemble the ROV in the time span that the PVC cement took to dry, PVC cement was applied to all connections to ensure a permanent bond.

Build Instructions

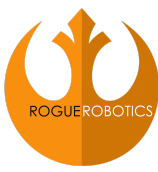
Materials:

- 1 10 ft. 0.5" ID PVC pipe
- 6 0.5" ID PVC tee connectors
- 8 0.5" ID PVC 3-way elbows
- 4 500 GPH Johnson bilge pump motors

Equipment:

- Marker
- Dremel
- Ruler
- Drill with 0.75" drill bit

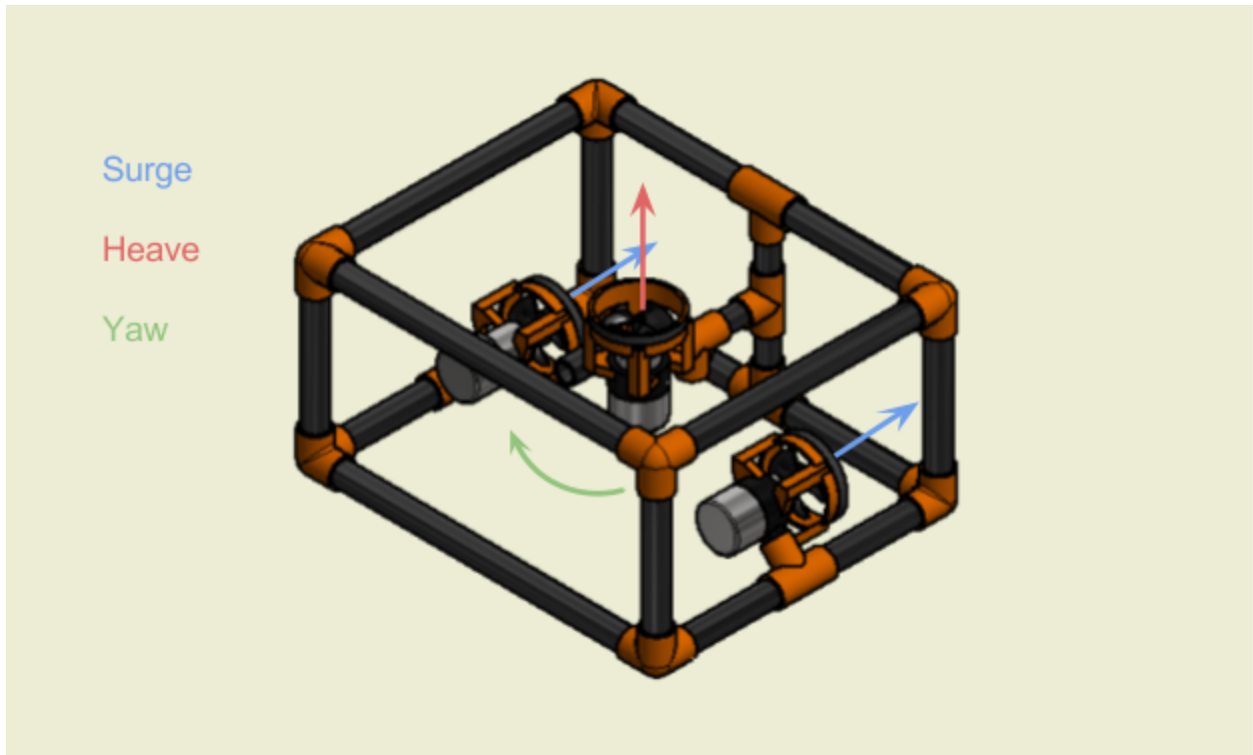
Note: PVC cement should be applied to piping prior to all connections.



1. Using the ruler, measure two 17" lengths of PVC from the 10 ft. PVC pipe, and mark at the appropriate dimensions.
2. Use the dremel to cut along the marks.
3. Insert a 3-way elbow at either end of each 17" PVC pipe.
4. Measure two 11" lengths of PVC, and use the dremel to cut along the marks.
5. Use the two 11" PVC pipes to connect the two 17" pipes via the 3-way elbows. This will create a rectangular structure.
6. Measure two 11" lengths of PVC, and use the dremel to cut along the marks.
7. Attach each of the 11" PVC pipes to the two 3-way elbows at the top of the rectangular structure.
8. Attach a 3-way elbow at the unoccupied end of each 11" PVC pipe.
9. Measure four 5" lengths of PVC, and use the dremel to cut along the marks.
10. Connect two of the 5" PVC pipes using a tee connector, and repeat for the other two 5" pipes.
11. Connect each paired PVC pipe structure to the two 3-way elbows at the bottom of the rectangular structure, so that the tee connectors point toward each other at 45 degrees above the horizontal.
12. Attach a 3-way elbow at the unoccupied end of each paired PVC pipe structure.
13. Measure two 11" lengths of PVC, and use the dremel to cut along the marks.
14. Connect an upper unoccupied 3-way elbow with its corresponding lower unoccupied 3-way elbow using a 11" PVC pipe. Repeat on the other side.
15. Measure four 8" lengths of PVC, and use the dremel to cut along the marks.
16. Connect two of the 8" PVC pipes with a tee connector, and repeat with the other two 8" pipes.
17. Secure one of the paired PVC pipe structures in between the upper unoccupied 3-way elbows, so that the opening of the tee connector points directly downwards.
18. Secure the other paired PVC pipe structure in between the lower unoccupied 3-way elbows, so that the opening of the tee connectors points directly upwards.
19. Measure two 4" lengths of PVC, and use the dremel to cut along the marks.
20. Connect the two 4" PVC pipes with a tee connector.
21. Secure the paired PVC pipe structure in between the two tee connectors pointing towards each other, so that the opening of the tee connector of the newly paired PVC pipe structure points into the frame.
22. Measure one 3" length of PVC, and use the dremel to cut along the marks.
23. Insert the 3" PVC pipe into the final opening of the tee connector pointing into the frame.
24. Attach a tee connector to the unoccupied end of the PVC so that the bottom of the "T" points downwards.
25. Mount the four motors to the frame by securing them to the openings of the four unoccupied tee connectors.
26. Drill 0.75" diameter holes into the PVC pipe in between in each set of connectors.

Thrusters

Volturnus has three thrusters mounted orthogonally for three actuated degrees of freedom: surge, heave, and yaw. This gives it the necessary maneuverability for a versatile deployment strategy while maintaining mechanical simplicity for powerful movement. The minimalist design means that low-cost bilge pump motors with attached propellers are able to provide sufficient thrust for the ROV.



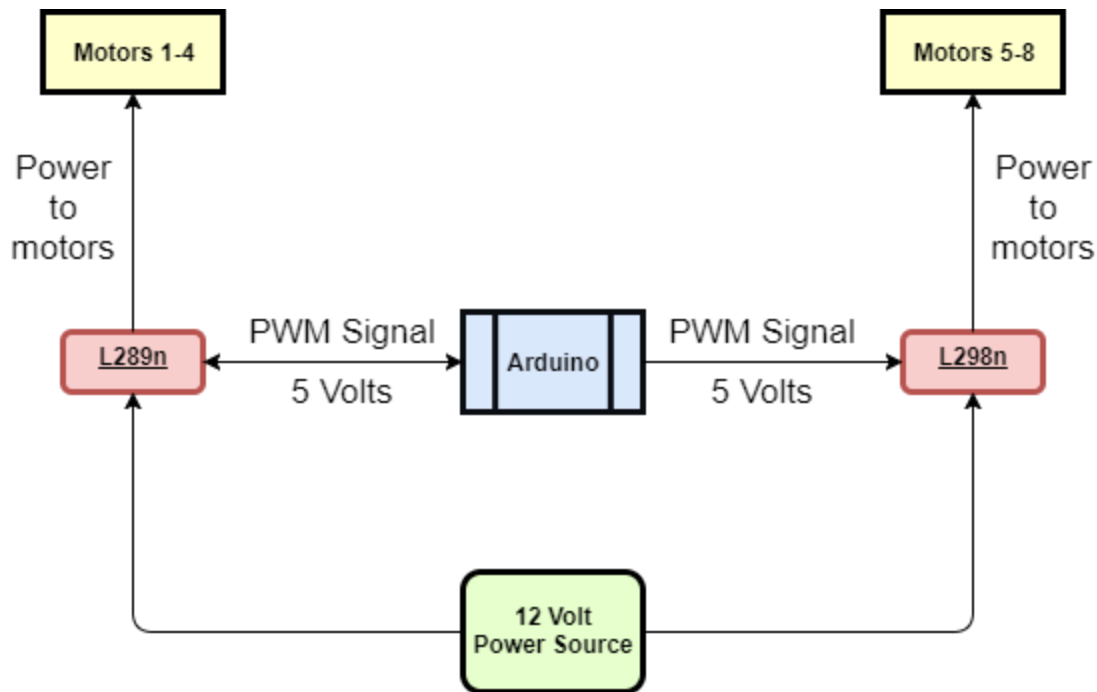
Electronics

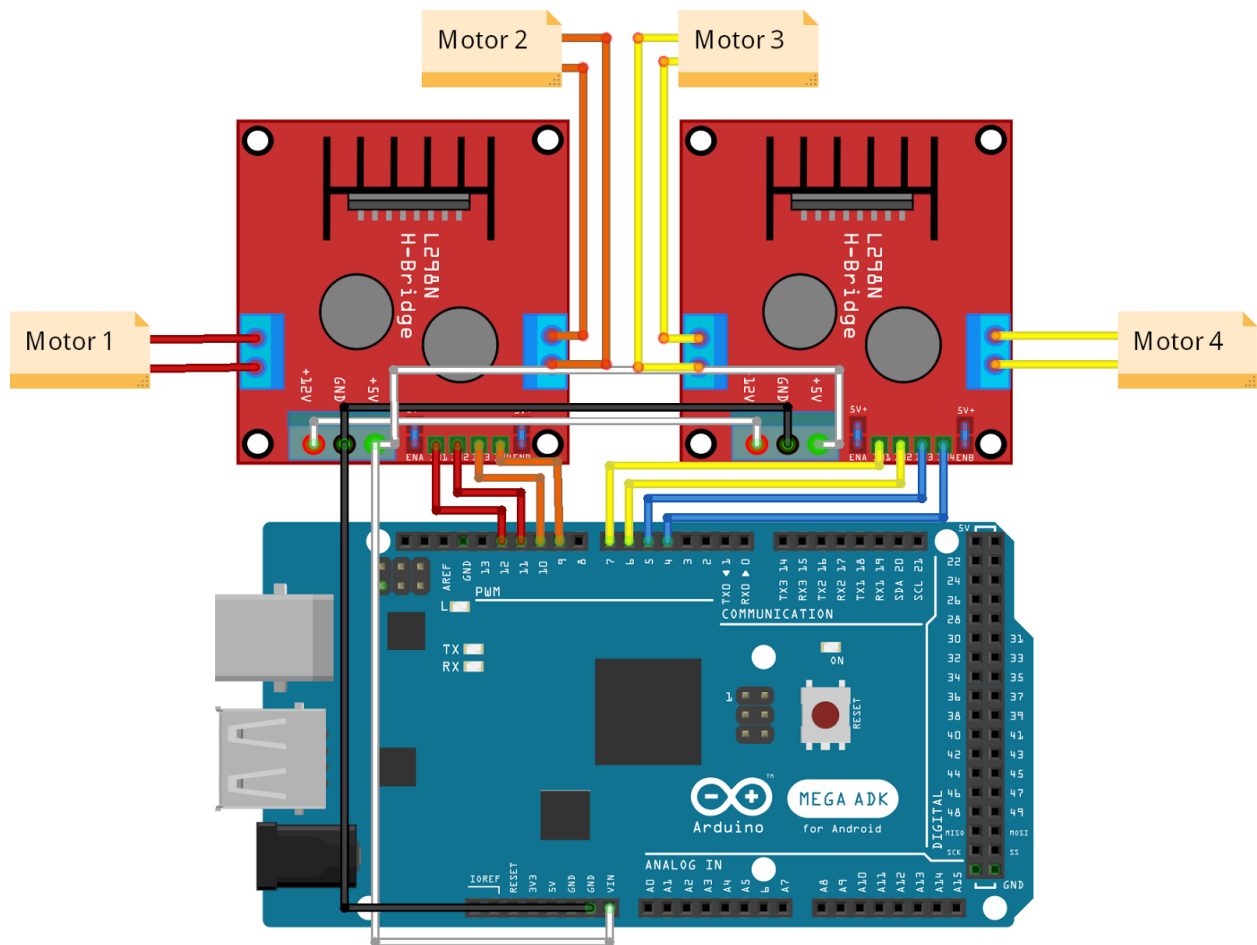
Motor Drivers

To keep electronics as simple, affordable, and accessible as possible, *Volturnus*'s electronic components are done entirely topside. This is made possible through a minimalist design and control scheme, allowing power to all the thrusters and claw to be delivered through cables inserted into a single lightweight tether.

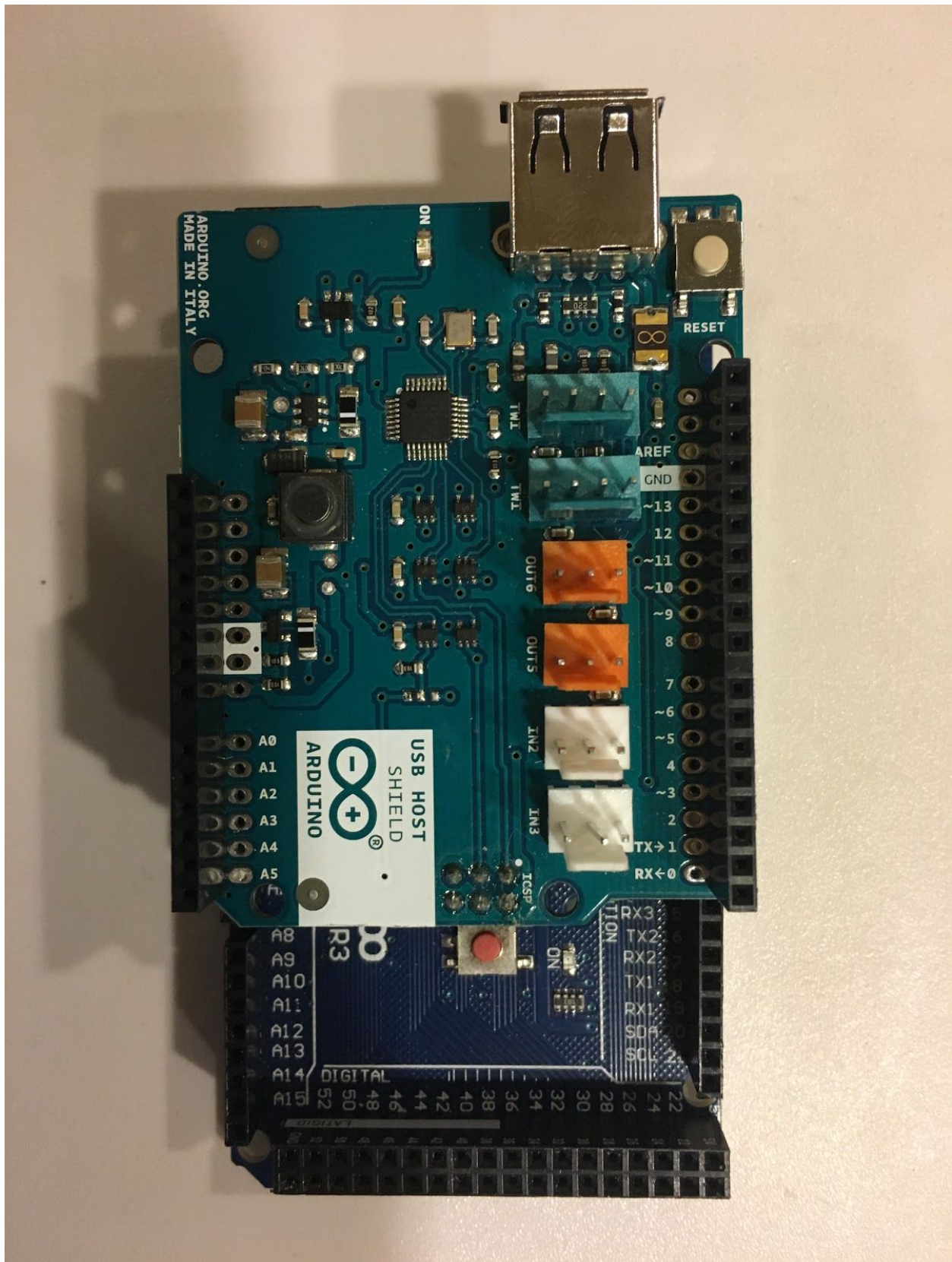
The primary purpose of the electronics on our ROV is to take input from a program and use this input to control the motors. First, the Arduino microcontroller reads pulse width modulation (PWM) inputs from two joysticks that act as potentiometers. In addition, the orientation of the joysticks tells the motors whether to turn clockwise or counter-clockwise. The Arduino then sends data signals to L298n motor controllers. These serve two purposes. For one, they can be used as h-bridges which can output a negative and positive voltage so that the motors can turn

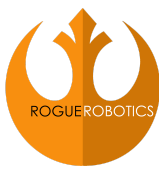
both ways. Secondly, they take in a PWM signal ranging from 0 to 255 so that it can output any voltage from 0 to 12 volts. Initially problems arose as we tried to ensure that the motor controllers could handle the current drawn by the motors. We had to do calculations using Kirchhoff's Law to calculate the current drawn from and the voltage needed for the motors. We then had to measure these values in practice using a multimeter. After this we tested our circuit and we found that it gave the robot the ability to turn and move forwards, backwards, and laterally at varied speeds.





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Cameras

The ROV uses a single IP68 waterproof car backup camera for underwater vision. ROV cameras are extremely important, as they are the primary and sometimes sole reference available to the pilot when navigating underwater. If multiple cameras are used or if a single camera is combined with a known reference or laser, it can additionally be used to take distance measurements underwater.

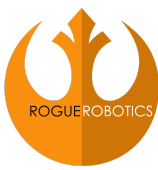
The car backup camera is connected to a USB video capture card, which is then plugged into the operator's laptop. The operator then runs a Python script to reverse the camera feed (since the camera feed is inverted due to its design as a car backup camera) and displays the camera feed in a pygame window directly on the laptop.

Water Contamination Detection

Ultraviolet light is able to detect OBAs (Optical Brightening Agents), chemicals that are commonly used in cleaning products. OBAs are often swept into the environment when products containing these chemicals are disposed improperly (i.e. poured directly into the sink); such chemicals can cause widespread damage. By using a cost efficient absorbent material, like cotton, the ROV is able to collect samples of liquid from bodies of water that may be tested for concentrations of OBAs. The OBAs are best detected after the sampler absorbent material is dried, as the chemical would not be diluted by the presence of water and other substances.

Budget

Table 2. Budget for <i>Volturus</i> ROV Materials	
Material	Price (USD)
PVC (frame and tether waterproofing) + cement	10.00
UV light	10.00
(4) 500 GPH motors + propellers	110.00 (80.00 + 30.00)
Tether	40.00
Waterproof connectors (strain relief + tether waterproofing)	20.00
Backup Car Camera	18.00
L298N Motor controllers	37.00 Arduino - 11.00 USB shield - 13.00



	L298N - 13.00 USB joystick / XBOX controller (re-used)
Total:	261.00

Logs:

1. Frame

The ROV frame has been constructed! The frame is a simple rectangular box made from PVC--this offers the most versatile and cost-effective design. Currently, our frame has dedicated PVC connectors for mounting motors. While this is certainly very easily modifiable, it might be easier to position motors with snap-on components.

Screw in motors

2. Tether waterproofing thing

Our tether has been attached--we opted for a lightweight tether with eight wires, two for each motor (3 drive motors and an additional motor that can be used for the claw). This allows our ROV to remain maneuverable in the water without getting weighed down by a heavy tether. Because electronics are being handled topside, there is no need for anything more than these wires.

3. Box

The topside electronics box is finished! The electronics box allows us to provide power and control through two joysticks and Sabertooth motor controllers. A cable with banana plugs connects to a 12V DC power supply, then runs through an in-line fuse, kill switch and watt meter for power and monitoring. The 12V then goes to the SeaMATE motor control simulation board, receiving inputs from the joysticks and Sabertooth motor controllers.

Instructions:

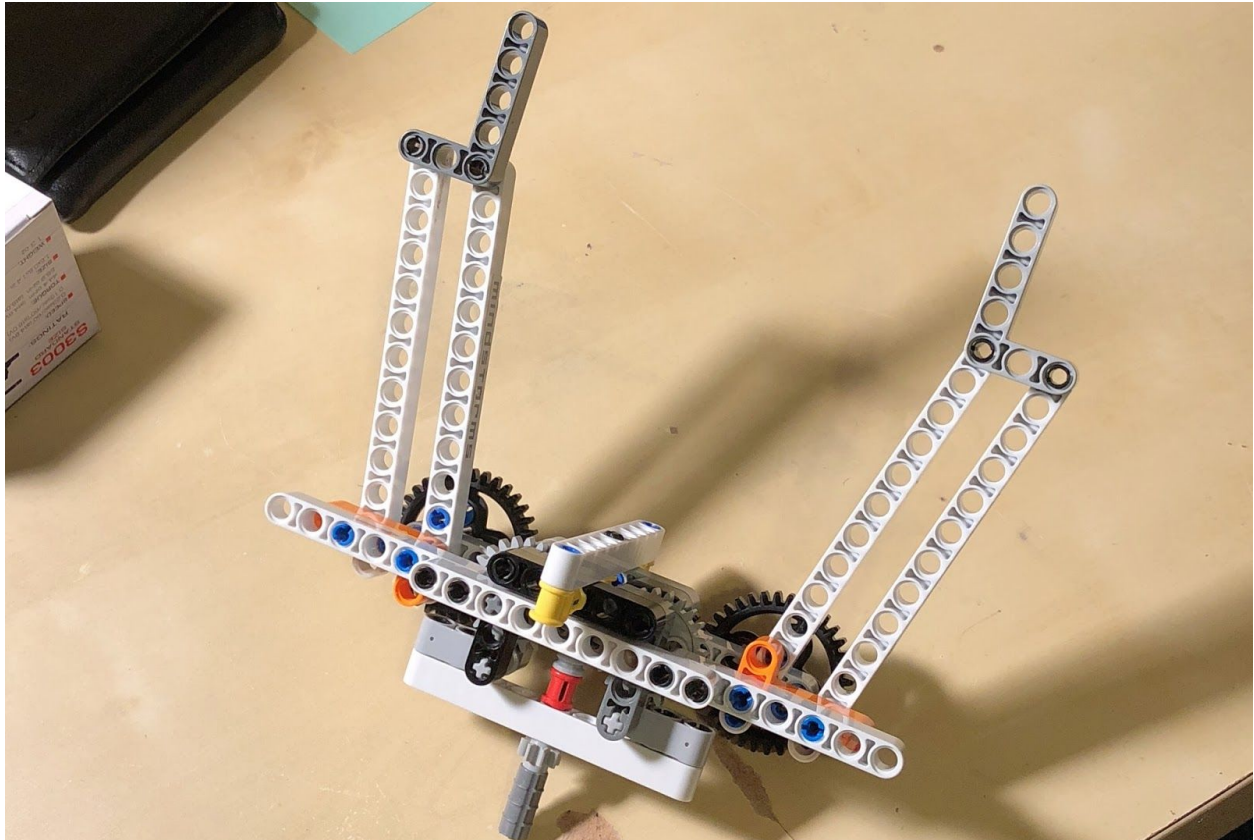
****Note:** The final electronics box is based off of the SeaMATE TriggerFish ROV's topside electronics box.

1. Follow the instructions in the following PowerPoint.
2. https://docs.google.com/presentation/d/1dUtlbWnvZd3Ftoe-ubnQnERUswa4mzj8zlySkJgx_E/pub?start=false&loop=false&delayms=3000&slide=id.g1c25bea16e_4_31

4. Claw

We have a few different claw designs for *Voltturnus*. We initially tried a simple Lego claw, but we found that it wasn't secure enough for our 500 gph bilge pump motor. We then thought about

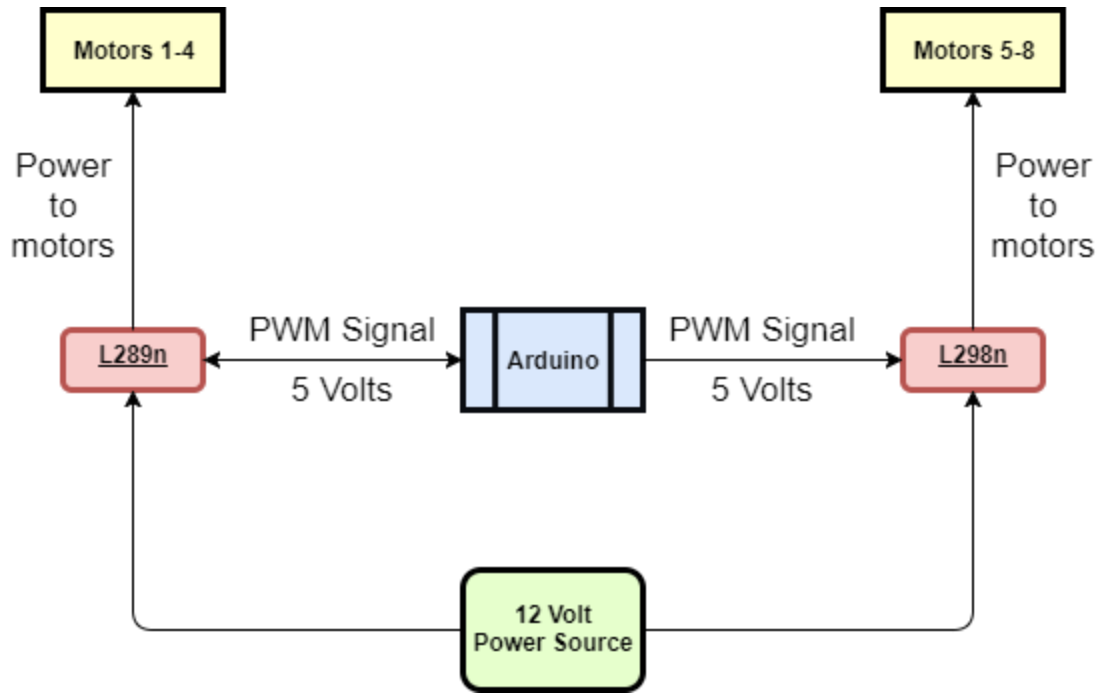
implementing a passive claw design--this would be cost-effective and free a motor for something else--but it would be difficult to adapt to the variety of different obstacles found underwater. Finally, we were thinking about building a more professional claw with 3D printing and metal gears, but we have not yet been able to implement it. We will need to run more tests in the future to see which claw design will work the best. Perhaps this is something that we should approach from an angle of modularity?

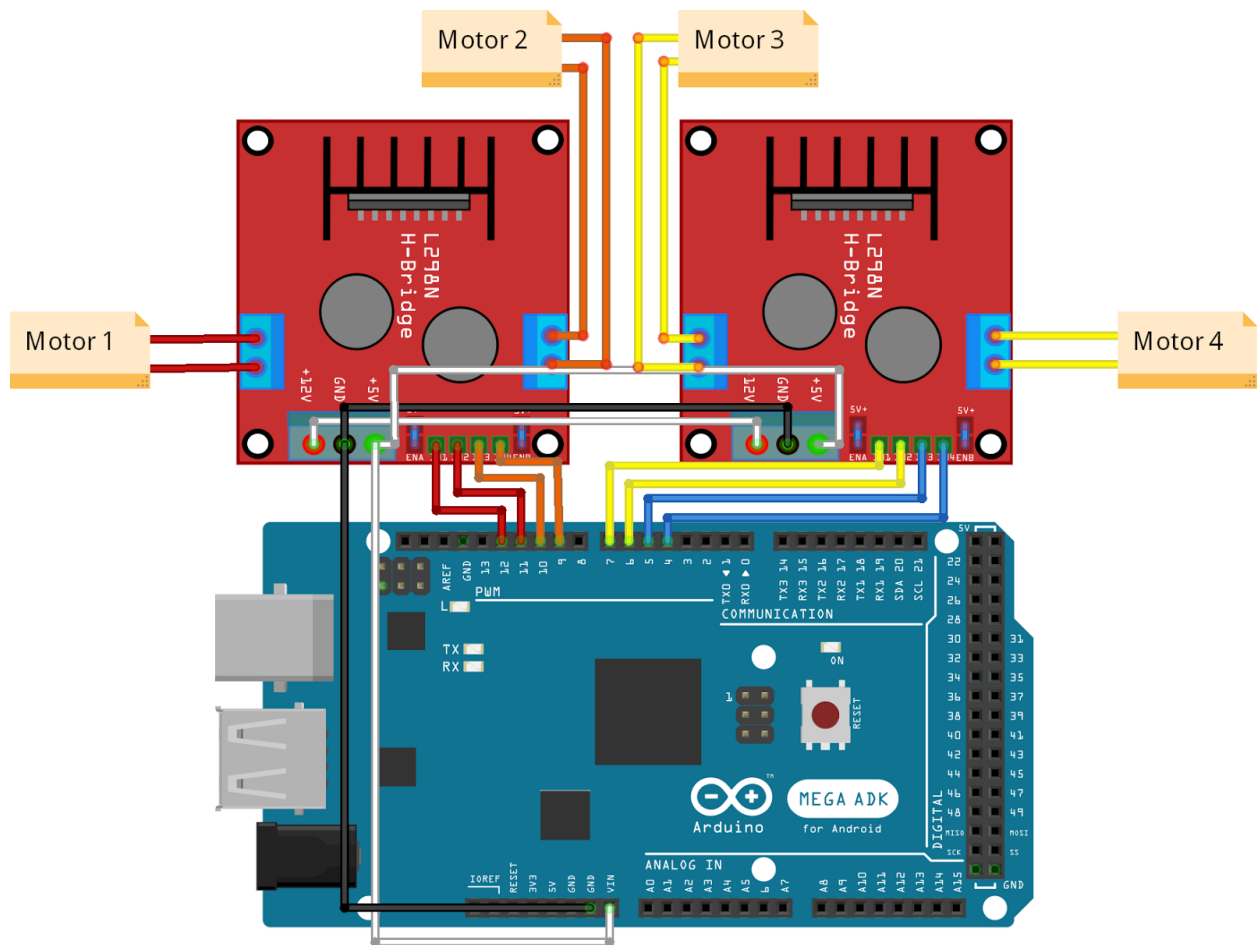


5. L298n motor controllers

We finished the final version of the motor controller circuit! The primary purpose of the circuit on our ROV is to take input from a program and use this input to control the motors. First, the Arduino microcontroller reads pulse width modulation (PWM) inputs from two joysticks that act as potentiometers. In addition, the orientation of the joysticks tells the motors whether to turn clockwise or counter-clockwise. The Arduino then sends data signals to L298n motor controllers. These serve two purposes. For one, they can be used as h-bridges which can output a negative and positive voltage so that the motors can turn both ways. Secondly, they take in a PWM signal ranging from 0 to 255 so that it can output any voltage from 0 to 12 volts. Initially problems arose as we tried to ensure that the motor controllers could handle the current drawn by the motors. We had to do calculations using Kirchhoff's Law to calculate the current

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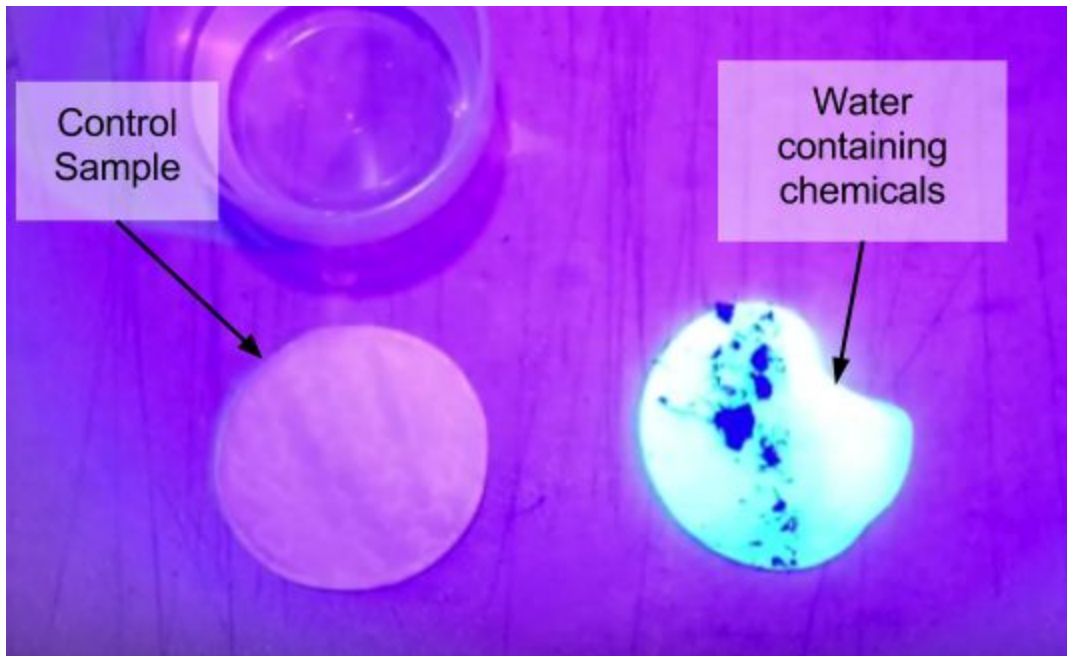
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6. Camera

Since we are using a low-cost backup car camera, the camera feed is inverted, but for intuitive control of the ROV this needs to be reverted back to a normal, “forwards” view. To do this, after threading the camera through the tether management cross, we plug the RCA plug of the camera into the video plug of a USB capture card. Using a Python script and the pygame library, we are now able to concurrently revert the camera feed and display it on the operator’s laptop.

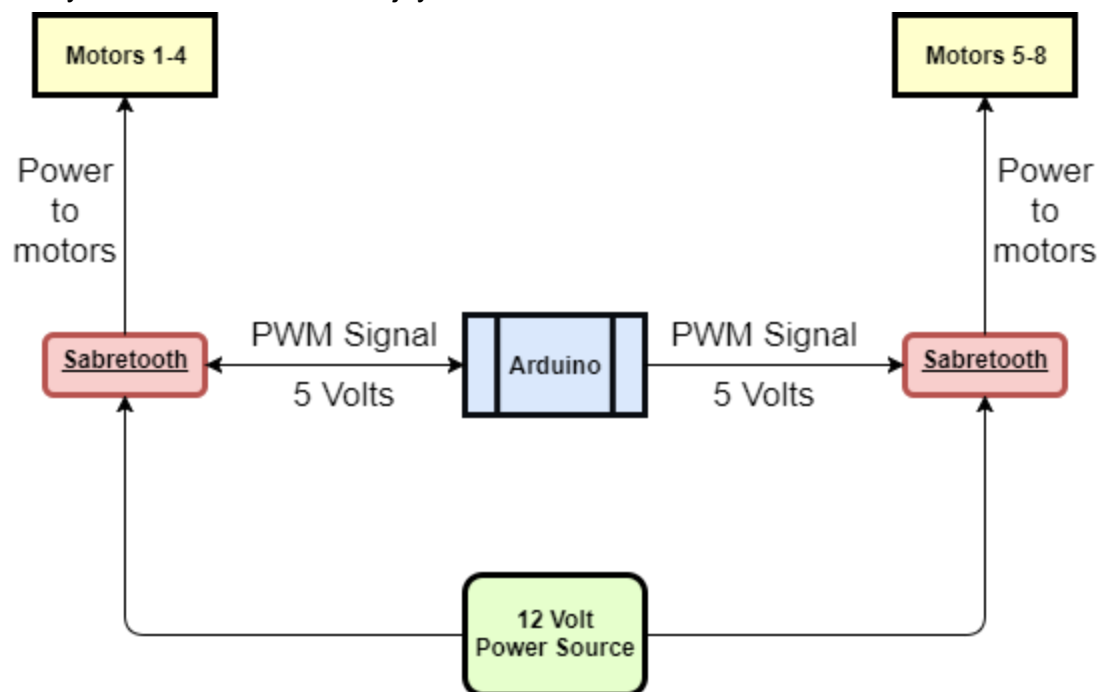
7. UV light

We needed a way to detect pollutants in the water. According to recent studies, shining ultraviolet light on water samples, pollutants will glow a bright color. We tested this with water samples collected by the ROV. We found that the UV light was able to highlight the sample that contained chemicals commonly found in laundry detergents. Thus, we successfully developed a low-cost method for find pollutants in water.



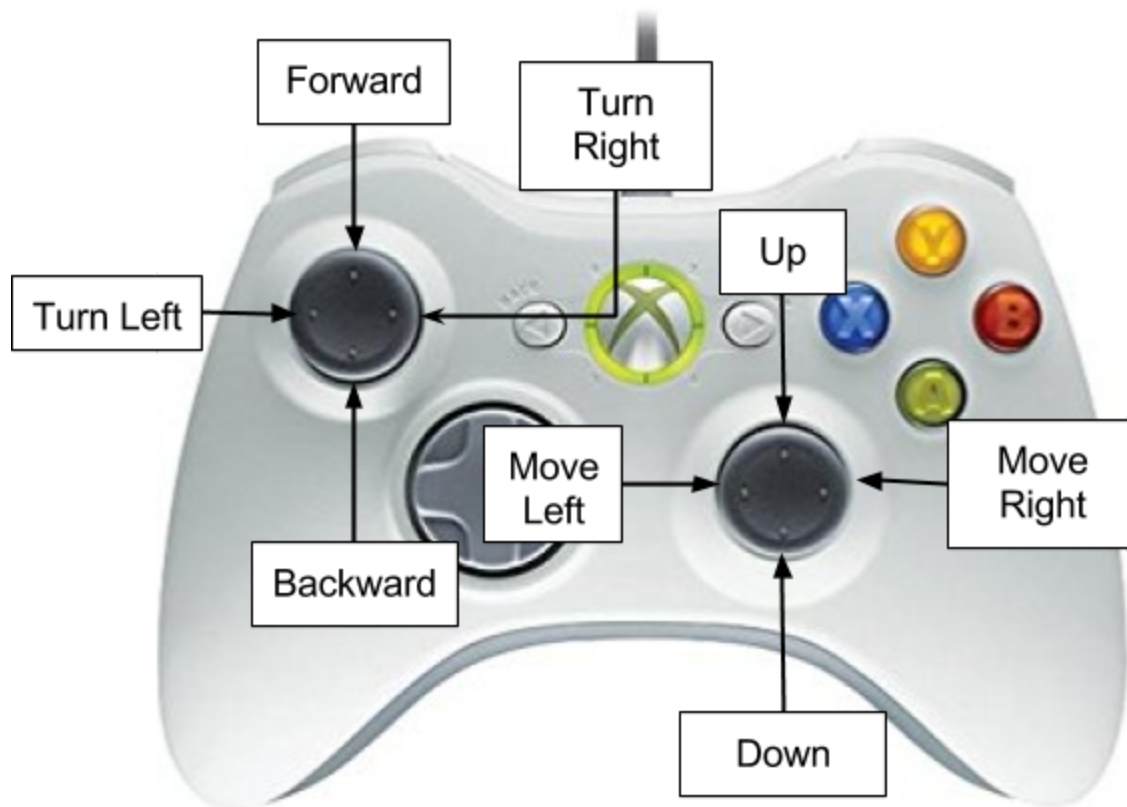
8. Alternative motor control - sabertooth motor controllers

We wanted to create a version of the electronics that was of better quality but was a little more expensive. We decided to use sabertooth motor controllers. Each one can control 2 DC motors and supply them with 12 amps each. The setup for this motor controller was really simple. We supplied the controller with 12 volts and input from 4 potentiometers. The controller then outputted 0 to 12 volts to the motors based on the potentiometer feedback. Thus, we could easily control the robot with 2 joysticks.



9. XBox controller

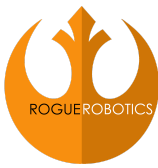
We needed an intuitive control scheme and a portable controller. We decided to go with the XBOX 360 controller. Although, this gaming controller has many joysticks and buttons, we only needed two joysticks to control all the motion on the robot. One joystick controlled forwards, backwards, and turning motion, while the other controlled lateral, up, and down motion. The joystick feedback was sent to a wireless receiver which was connected to a USB Arduino shield. We struggled with the receiver as the controller kept dropping its connection. We solved this by doing several power cycles. Finally, we had developed a control scheme that was user-friendly and effective.



10. Buoyancy

We needed a way to easily adjust the buoyancy of the ROV depending on the density of the body of water that the robot is in. We tried attaching various “ballasts” to the ROV using environmentally friendly duct tape. We started by taping rocks to the robot to weight down different parts of the robot. This proved to be impractical as these rocks couldn’t be easily adjusted in a real life scenario. We then tried to tape styrofoam to the frame, but this was impractical for the same reasons as the rocks. We finally added Arizona Iced Tea bottles which are perfect as they can be filled with water to easily adjust buoyancy at any time.

11. Possible future extensions/plans



We're thinking about what to do next for our ROV. We would like to be able to implement filtration technology in addition to the detection technology that we already have, but we were also considering moving electronics to bottomside. This would greatly enhance our ROV as we could use more powerful thrusters and take in more sensor data. We would also like to try to test our robot in more real life scenarios. If we could actually monitor a body of water for an extended period of time, we would be able to see how to improve our robot so that it can be used commercially.