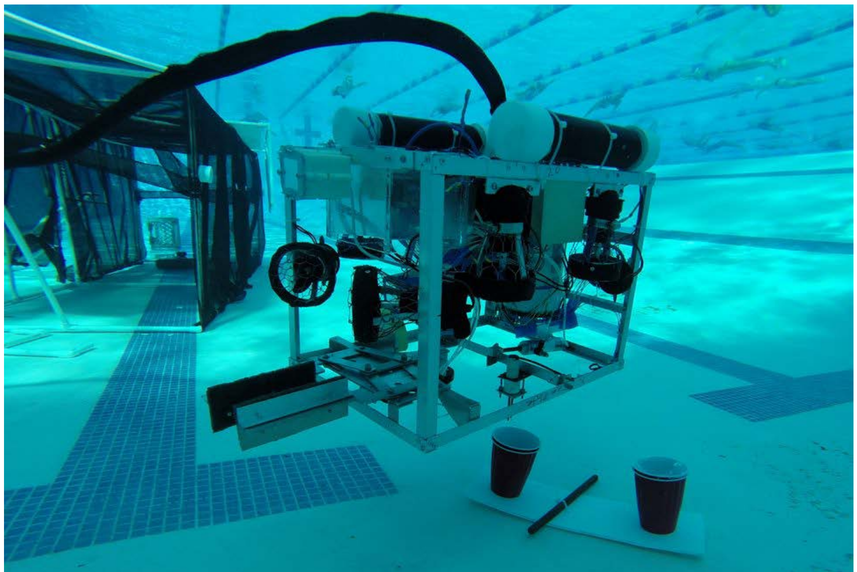
Aptos Mariners Robotics, LLC.

Aptos High School • Aptos, CA 95003

*Featuring: "**The Hammerhead**"*



The Hammerhead

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Abstract

Aptos Mariner Robotics LLC constructs high-quality underwater remotely operated vehicles, specifically designed to efficiently and effectively meet all client's mission requirements. Our most advanced robot yet, The Hammerhead, has been explicitly designed for the precise analysis of underwater shipwrecks as well as their impact on the surrounding environment. This research is integral in obtaining important knowledge about shipwrecks, both past and present, and data on subaquatic anomalies, particularly in the Thunder Bay region of the Great Lakes. The Hammerhead is equipped with breakthrough technology such as a dynamic claw, cameras that enable cutting-edge stereo vision, highly accurate laser measuring devices, and a precise conductivity sensor – all integrated into a compact chassis. Such advanced technology allows The Hammerhead to accomplish all desired mission specifications – maintaining the superb quality of robots that Aptos Mariner Robotics LLC continues to uphold.

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Early Frame Prototype

Safety

The safety philosophy of Aptos Mariner Robotics LLC is based on the complete protection of all company members as well as the continuous safety of the robot itself. Aptos Mariner Robotics requires strict adherence to all safety protocol and the company's safety specialist ensures that all faculty are taking the proper safety measures.

Throughout the development of the ROV, company members received training from mentors on how to use all power tools and other devices to ensure that associates of the company do not harm themselves from misuse. All team members are also required to have a spotter when using any power tools to be able to assist in case of an emergency. A first-aid kit is always easily accessible while the company is constructing or operating the vehicle; however, it has not been utilized this season due to our extensive precautionary measures. Before operating the ROV, the company's deck crew reviews the mandatory safety checklist to ensure that all members and the robot are protected during the mission run. The checklist directs the crew to confirm proper setup, including ensuring that there are not exposed electronics, that the power is connected correctly, and that there are no tripping hazards on deck.

The Hammerhead robot has been specifically designed to complete the mission tasks while simultaneously meeting the proper safety requirements. The ROV is equipped with several safety features to ensure that all operators and the surrounding environment are protected. There are motor shrouds around the ROV's propellers to prevent any harm to the crew and underwater ecosystem. All sharp or rough edges on the robot's chassis are also removed in order to reduce the possibility of an accident occurring that involves the crew. The robot is also protected from any harm or damage through the installment of strain release on the tether to avoid disconnecting any wires. Fuses and a buzzer are connected to the electrical box to prevent the electronics from being destroyed and ruining the robot.

Aptos Mariner Robotics LLC upholds the highest standards to ensure the safety of all team members and our robot. These standards have applied to all phases of development and will continue to be monitored throughout the competition.

*See appendix for Safety Checklist

Finances

Budget

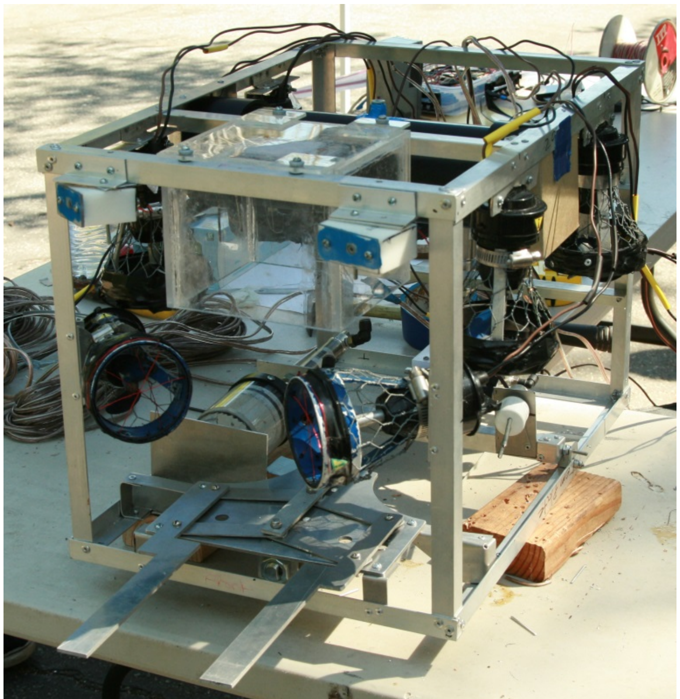
Category	Budget	Actual
Mission Props	$150	$180
Mechanical	$400	$849*
Electronics	$550	$877*
Tools	$420	$10*
Software	$0	$0
Cameras	$450	$420*
Stereo Display	$500	$520*
	$2470	**$2856**

** Excludes donated labor and material*

Donations

Donators	Donations	Est Value
Santa Cruz County Office of Education	Purchase orders	$2000
Intuitive Surgical	Cash Donation	$500
David Patino, WAAE	3D printing and CNC operation	$200
Mercury Metals	Aluminum sheet metal	$50
Johnson Family	Tether sheath	$250
Makers Factory	3D Printing	$70
Pajaro Valley Fabrications	Water jet cutting for claw	$50
Autodesk	AutoCAD educational licenses	$200
Jeske Family	Teak	$40
Total	Total	$3360

DESIGN RATIONALE



The Hammerhead Chassis

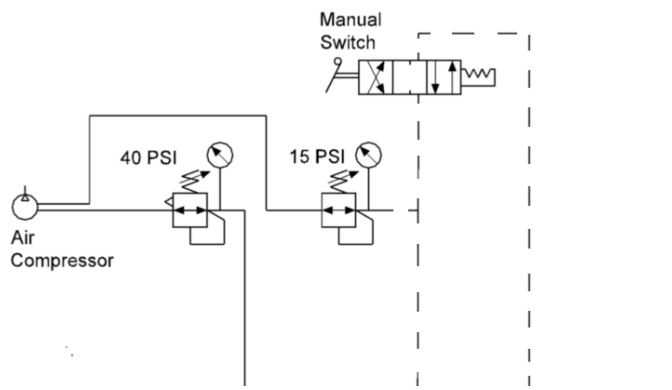
FRAME

The frame of the Hammerhead was limited in size compared to previous years. This is due to the size of the hole in the ship that the robot needs to navigate inside of. The frame is 36cm in height by 36cm in width by 51cm in length. The main tools include a large laterally moving claw, an agar leech, stomper, and conductivity sensor. These are mounted on the bottom of the ROV to keep the majority of the weight down on the bottom of the craft. Since the frame size is limited, mounting all of these tools in a way so that they can all operate without interference became a major issue. The mechanical team also had to ensure that none of the turbulence from the motors would be blocked by the mission tools. The frame is constructed of 1/16" thick ¾" x ¾" aluminum angle which is strong, lightweight, and easy to work with. Each piece is fastened with two rivets to provide structural integrity and gussets were also used to make the corners very solid.

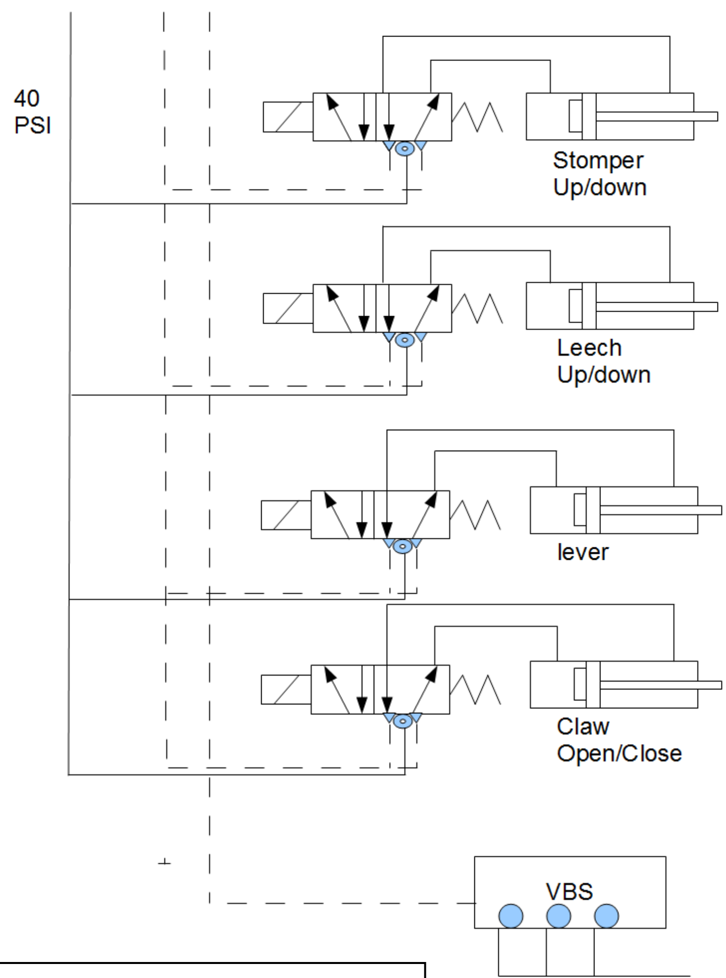
PROPULSION

The ROV is propelled by 8 329.8 Lpm (liters per minute) bilge pumps equipped with propellers, four of which are vertically positioned motors. The vertical motors are positioned in the corners so that the ROV is able to achieve pitch. The lateral motors are mounted directly in the corners in an "X" configuration. This means that they are at a 45 degree angle to the frame. This maximizes the space inside the frame as well as provides a superb strafing ability. This configuration is key because the robot needs to be able to strafe as well as have a small silhouette to make navigation inside the ship easier.

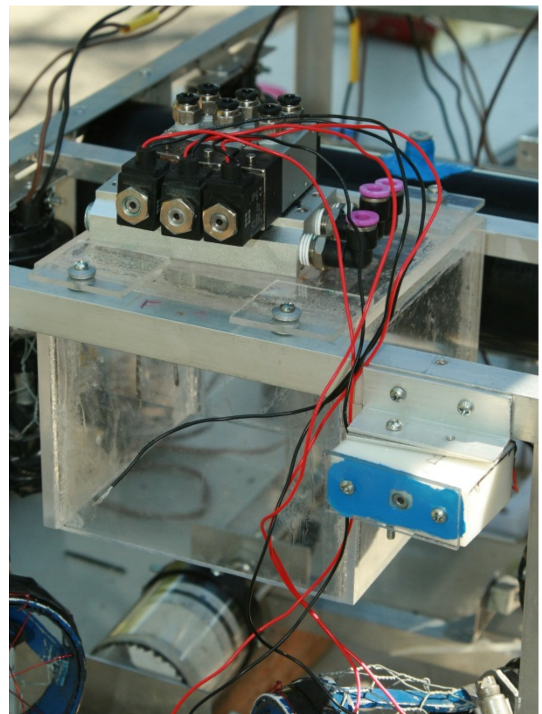
Pneumatics



Surface Pneumatic Control



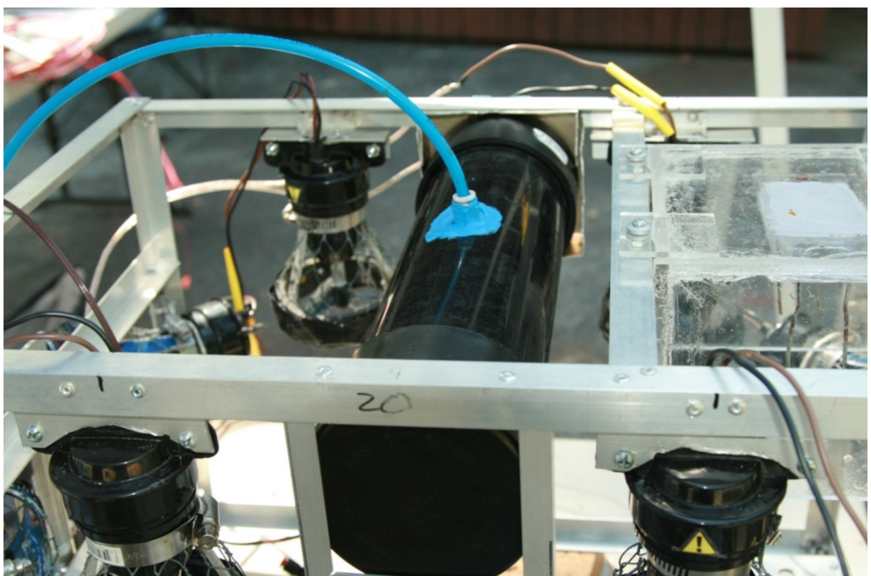
Pneumatic Payload



Solenoids Ready for Mounting

Active Buoyancy

This year the buoyancy system uses a similar method to previous years' systems. The three-piece system includes static chambers that also double as housings for the down electronics, the pneumatics system, and an active buoyancy chamber. An active buoyancy chamber is necessary for this mission because the ROV needs to be able to lift a heavy plate, carry agar, and move two bottles as well as have very fine positioning. The active buoyancy chamber is operated by running a pneumatics hose into it, which fills it with air. There are holes on the bottom of the chamber so that once the canister is filled up with air, it doesn't explode. There is a range of 3200 - 6000 cm^3 of buoyancy. To descend, the air is simply sucked out using our C.I.S.A (Custom Integrated Sucking Apparatus) which then floods the tank, causing the ROV to descend. The buoyancy chamber is located at the top of the ROV and centered to counteract the low center of mass due to the placement of the mission tools. Since our static buoyancy chambers also double as pneumatic encasings and down electronics, space is saved in the already small frame.



Active Buoyancy Chamber

Activate Buoyancy

$$Fb_{active} = V(d_w - d_a)g$$

$$d_w = 1000\, {}^{kg}/_{m^3}$$

$$d_a = 1.3\, {}^{kg}/_{m^3}$$

$$V = \pi r^2 L$$

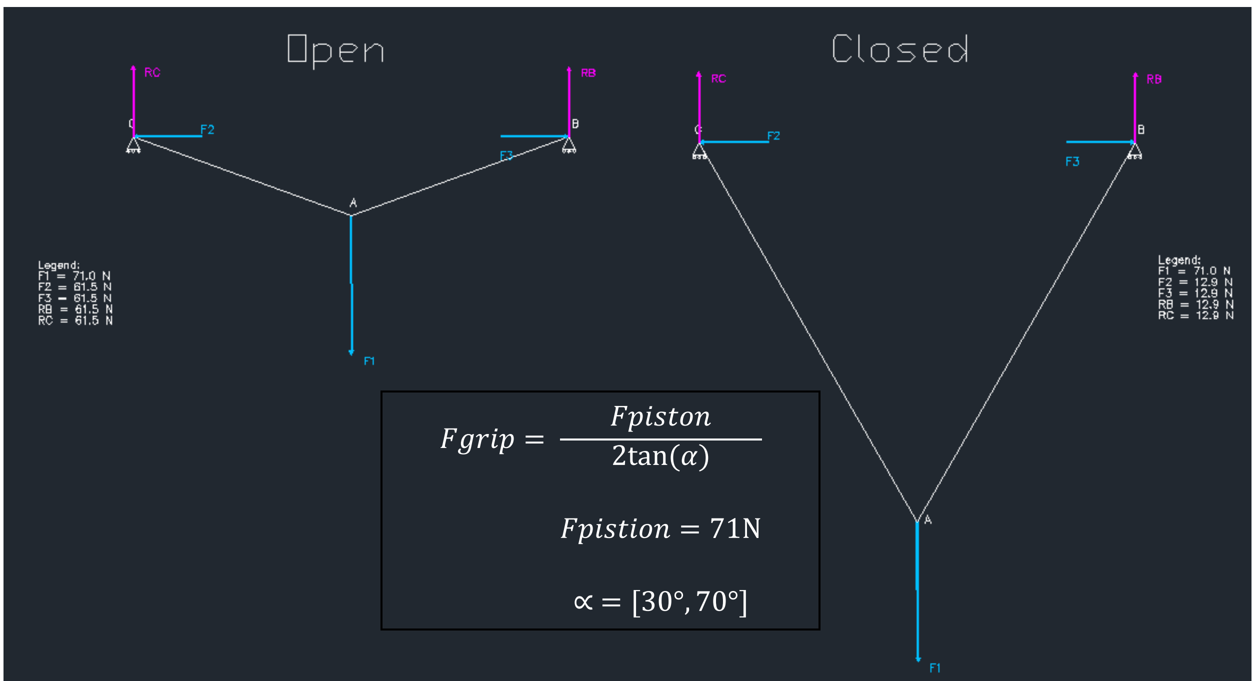
$$r = .05m, L = .35\text{m}$$

$$Fb = 27\text{N}$$

Mission Tools

Manipulator (The Claw)

When designing the claw, the team considered the tasks the claw needed to accomplish and the qualities required to perform them. For example, in order to retrieve the glass and plastic bottles, the claw needed to have a maximum opening of at least 9 cm. Fortunately, many of the tasks this year necessitated similar attributes to the previous year's claw. The most prominent being: linear motion for opening and closing, long and narrow arms, tall grips, and a 5.1 cm piston stroke. With some calculations the team discovered that the angle between the connectors and the center shaft should be 30 degrees when fully closed and just under 90 degrees open, in order to provide optimum gripping force and to prevent the claw from getting stuck in a certain position. Within these angles the claw exerts a gripping force from 61N (open) to 12N (fully closed).

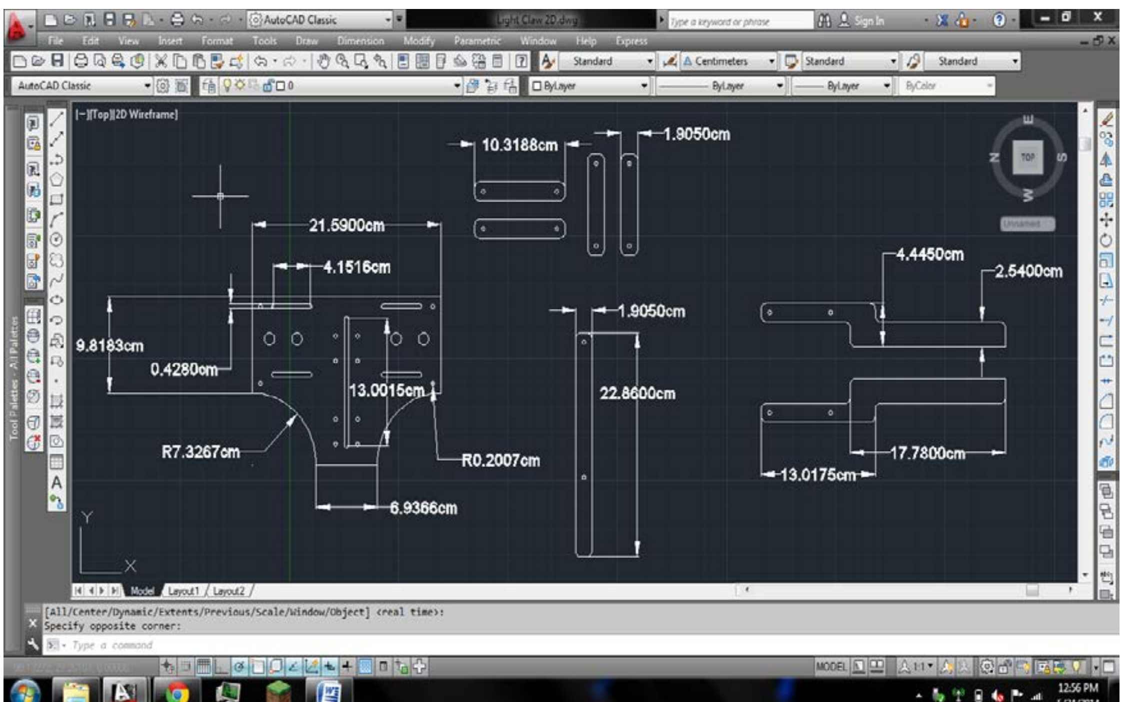


Claw Force Computations

The materials that the mechanical engineering team decided would be best for the claw were: aluminum sheet that is used for the claw mount, center shaft, connectors, and the arms. Also, aluminum angle, rubber, and coarse sponge compose the claw's grips. The components are held together using #6 screws with washers and lock nuts. To give the claw enough power, a 2.7 cm bore piston is used. The center shaft is connected to the piston with a block of aluminum with threaded holes for the piston shaft and the screws on the center shaft of the claw.

In order to fit into the more compact space of the ROV, the piston is mounted underneath the claw rather than behind it. The claw mount is a thick sheet of aluminum with slots cut into it to provide guides for the screws in the center shaft and the arms, allowing linear motion without the claw moving forwards or backwards; it also has holes to reduce mass and drag. The grips on the arms are wide to allow the ROV to have a large surface area with which to hold onto objects.

The creation and completion of the claw was a long and sometimes arduous task. First the mechanical engineering team thought of and drew a preliminary design, which was then constructed into a full-size model of the claw using cardboard and wood. This allowed the team to fine-tune the design and make sure everything would operate properly without the cost of making a claw out of metal or acrylic. Once the claw design was finalized, the mechanical engineering team gave the CAD designers sketches and measurements; from there the CAD designers made 2D and 3D representations of the claw, of both the entire mechanism and the individual parts. This allowed the mechanical team to use a CNC machine to make the components. The first CNC claw was cut from ⅛ inch acrylic. This version was used to confirm the dimensions. This also ascertained that the claw worked when made out of thicker and less pliable material. After tests were completed and adjustments were made to the design, the final claw was cut out of aluminum and assembled.



Claw Component CAD Drawings

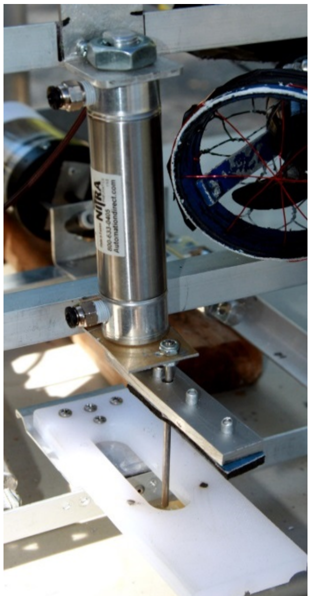
Conductivity Sensor

In order to measure the salinity of a solution, the conductivity sensor measures the resistance of the liquid. As the salt concentration in the liquid increases, the resistance goes down. The Hammerhead's conductivity sensor is designed to measure this resistance, because it varies directly with salinity. The mechanical team designed this specifically to complete the mission of measuring the conductivity by inserting probes through a plastic wrap cover. The conductivity sensor is attached to an arm that swings down when it is in use. To keep from constantly using power, the conductivity sensor only has power when the arm is lowered. The conductivity sensor consists of two screws protruding from a plastic cap. The screws are sharpened, and one is charged with 5 volts. The resistance across the two screws is measured using a voltage divider. When it's ready to be used, the two sharpened screws are lowered onto the container, poking holes in the plastic wrap and measuring the salinity of the solution within.

Microbial Extraction Device (The Leech)

Leech Payload Tool

The Microbial Extraction Device (MED), or better known as the Leech, was designed to collect a sample of chemosynthetic bacteria and photosynthetic Cyanobacteria from their respective locations on the seafloor. The current leech is the third model for the proposed task, each having their respective strengths as well as weaknesses. The current leech is a 12 volt model motor in behind a cylindrical plastic container that will hold the collected bacteria from the propeller, which is in front of the holding container. The leech can hold more than the required 150 mL of bacteria. It is mounted on the rack which is a pivoting piece of angle to allow maximum maneuverability during the remainder of the mission.



The Stomper

Stomper

The stomper is a specialized manipulator engineered to pick up horizontal objects, such as a plate. The stomper is constructed to be very thin so that the nearby motor, microbial extraction device, and conductivity sensor can still operate at maximum capacity. It is constructed of a piston pushing an aluminum bar down onto a plastic platform with a soft pad between the two, so as to not damage the plate that will be picked up with the stomper. The mechanical team chose to construct this design over a rotating claw because, with the stomper, we save space and time, as well as it being much easier to operate. It is also located on the back, because it wouldn't fit on the front with the claw and the other motors.

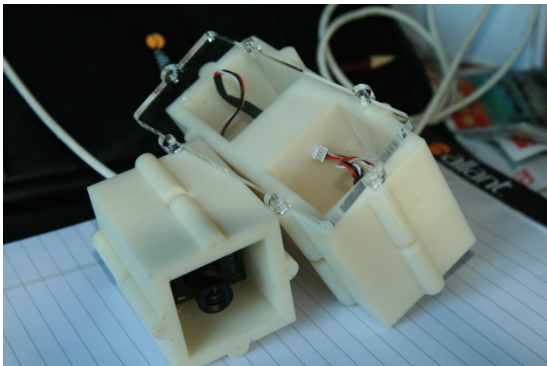
Lasers

The Laser Positioning System (LPS) consists of two 650nm red lasers mounted on the front corners of the frame. They are each set in a block of acrylic with a silica gel packet. In front of each laser is a clear Plexiglas lens set on top of an RTV gasket. The back of the enclosure is a thin aluminum sheet with a rubber gasket and caulking around the power wires that go to the Arduino. This is held together by a pair of screws that go through the acrylic block. The lasers are controlled by the Arduino-nano that is part of the ROV's payload. They run off of 5V DC which is supplied by a voltage regulator that the company specifically designed. The mounts are made so that adjustments can be made in both the X and Y orientation of the casings by tightening or loosening screws. This tool is used to make sure that the robot is a specific distance from the shipwreck to allow the operators to perform trigonometric calculations to find the length, height, and width of the wreck. When the dots converge on the wreck, the operators know that the ROV is at the exact right distance to perform the task.

Laser Positioning System

Command and Control

Cameras



Mono and Stereo Camera Housings

Stereo Head Mounted Display

The ROV has 7 cameras, 3 single mounted cameras, and 4 mounted in stereo, creating 2 sets of stereo cameras. Each camera is mounted to the ROV in a custom designed, 3D printed camera cases. The single cameras feed the signal into both eyes of the stereo goggles to give a single image, while the stereo mounts feed both signals from the cameras eye distance apart to the goggles for the stereo effect.

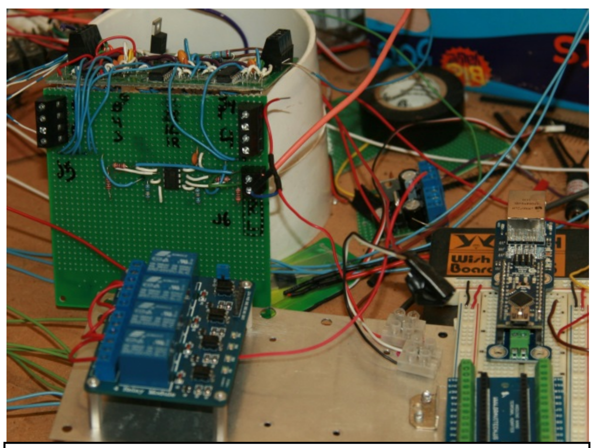
Goggles

The decision was made to design goggles that would allow the pilot to drive the ROV using stereo vision. 2 pairs of 3D goggles made for flying RC airplanes were bought that each took one video signal and split it into 2, giving a fake 3D image. Both pairs of goggles were taken apart and the power board and the video board were transferred from one pair and put into the other. Doing this allowed us to get a video signal from one camera and feed it to the left eye, while getting another video signal from another camera and feeding it to the right eye. With stereo vision goggles, the pilot has depth perception, making the ROV's tasks significantly easier.

Electrical Box

The Electrical Box Begins with a ten-gauge wire leading from the battery to the main box. This wire has a fuse to prevent excess current from being drawn off and helps protect the box from being overloaded with current. Made of handcrafted teak, the Box (as it is affectionately referred too) combines safety, functionality and style. Teak was chosen because it is durable and functional as well as aesthetically pleasing. The anti- reverse current circuit is at the beginning of the box. The circuit uses a combination of relays and diodes to prevent current from flowing backwards into the motor drivers. In the event that the power leads were mistakenly put into the battery incorrectly, not only would a loud warning alarm sound, but also, the system would prevent the flow of current in the opposite direction, protecting the motor controllers and the rest of the box, ensuring that a quality product is maintained. This was done to insure safety as well as product quality and to make absolutely sure that the electrical box would not fail. After the anti-reverse current circuit comes the Arduino; with its spider like design helps power and run the motors with the help of eight Pololu motor drivers, each controlling a separate motor on the ROV. The Arduino was chosen because it is easier to wire and control. In addition an Arduino allowed us to control the motor controllers directly by the software. This design was chosen over a daisy chain and breadboard because in the breadboard wires kept coming undone leading to difficulties in completing the required missions. Leaving the box, the motor controllers attach into a tether port. The plugs are connected to the bus bars with pins. This design allows for a detachable box, leading to easier travel and handling in the use of the ROV.

Down Electronics



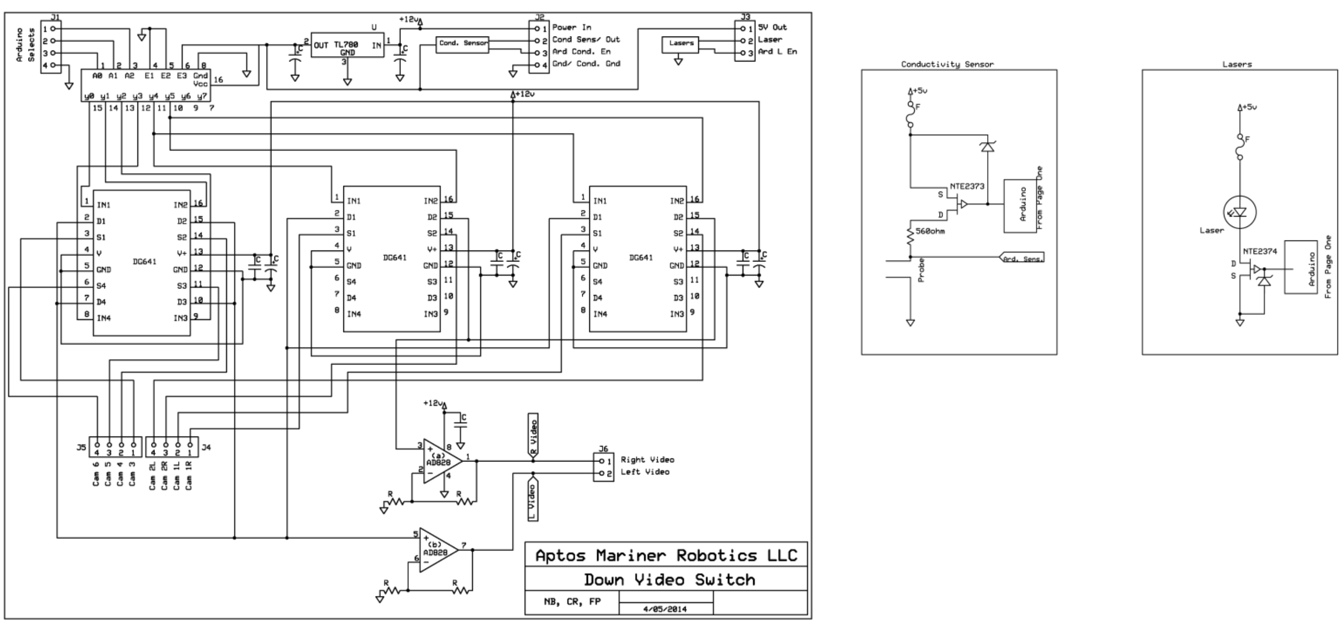
ROV-side electronics on the bench

One of the main features on the ROV is its new down electronics tube. Inside the capsule there are several different modules. One is a video switcher that allows for a smaller tether by requiring only two camera wires to travel to the surface rather than two wires for each camera. The second is an Arduino that communicates to our computer on the surface and the third component is the relays that are used to control our solenoids.

This year one of the team's goals was to build a smaller and less cumbersome tether. The electronics team found that the majority of the company's previous tethers were composed of camera cable. The team decided that the optimum way to lessen the quantity of cables was to construct a video switcher that would require only two camera wires to function, (One for the left side of our stereo cameras and one for the right side to connect to the pilot's goggles). Our video switcher board begins with the Arduino's input into a demultiplexer which then "talks" to three different video switchers. The three video switchers have camera sources from all of our cameras and send the one chosen by the demultiplexer to a voltage amplifier. The voltage amplifier was added to ensure that there is a strong and clear video signal to the computer, which would provide a good image on the screens and goggles for the pilot. All of the components are powered by a 12V power supply, except for the demultiplexer which employs a 5V regulator to consistently supply it 5V. The board also houses the circuits for the conductivity sensor and the lasers.

The other main component in the down electronics capsule is the Arduino which "talks" to our computer on the surface through a CAT5 ethernet cable. The capsule also houses the relays which are connected to pins on the Arduino and power the solenoids. The relays are reverse sensing; this means that they are tripped when the pin they are watching is turned off.

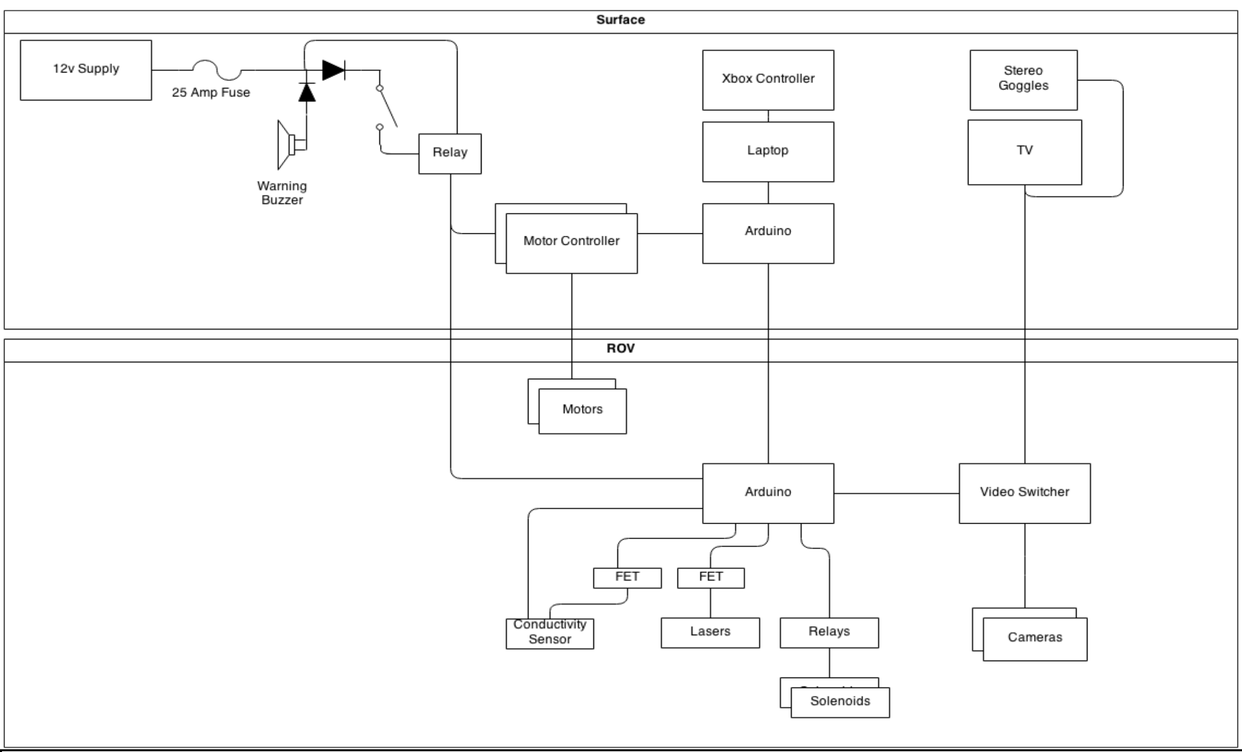
The down electronics capsule was built out of a 3" PVC pipe. One end is sealed with an epoxy resin to waterproof the capsule. This end has all the appropriate wires traveling through the waterproofing material to the components inside. The other end is sealed with a PVC plug. The different components cannot come into contact each other since there is exposed metal one each separate module. The capsule is filled with expanding foam to create an insulating wall between the parts, allowing them to fit tightly together without the risk of shorting out.



Down electronics diagrams

SOFTWARE

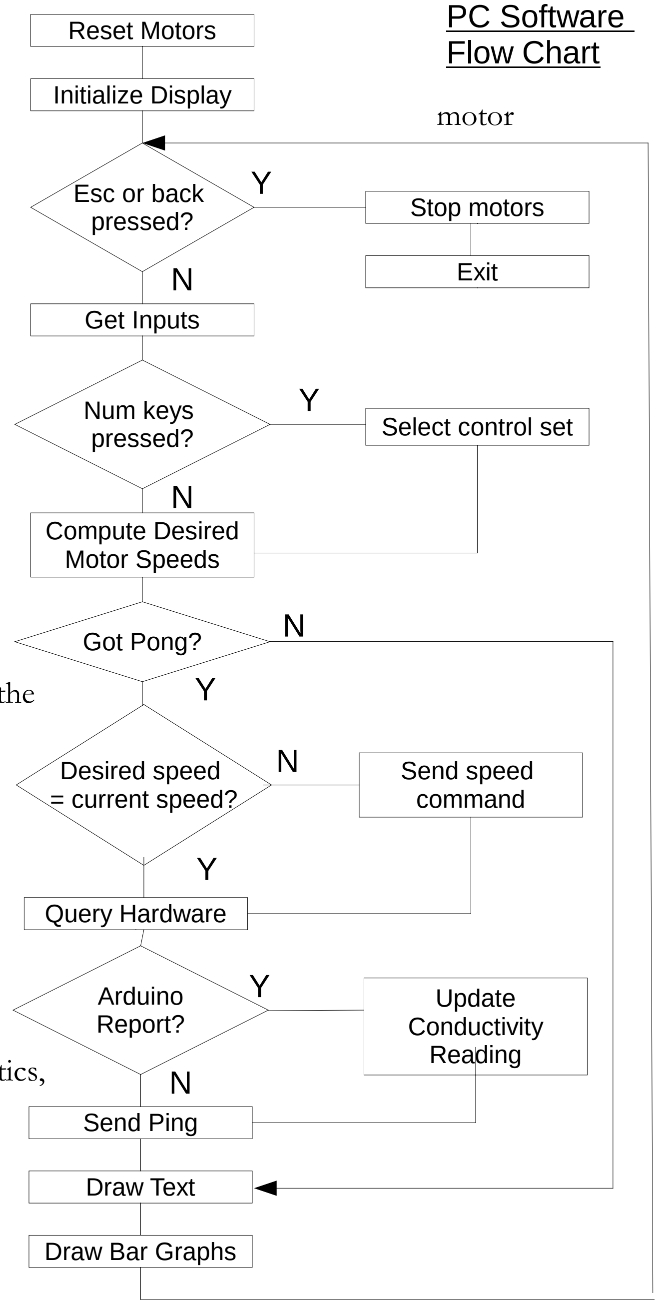
The ROV software is made to be as versatile as possible while simultaneously being simple and quick to setup and use. All the code on the computer is written in C#, and Arduino code is written in Arduino's variation of C. The motor control software on the computer runs via a main loop, which first checks the state of the Xbox controller, and calculates the desired values for each motor. It then sends that data over serial to the surface Arduino. It then moves on to draw on the screen the graph that represents the motor states. It also receives the data from the Arduino, which includes error codes, conductivity results, and regular state check-ins which are displayed on screen. The surface Arduino has two main parts. First it must separate all incoming commands. Anything coming from the computer it must decide if it has to deal with it or relay it on to the down Arduino. It also relays any messages received from the down Arduino on to the computer. After it has separated the commands, it will take any it was supposed to deal with, such as a motor control command and set the motor to the desired speed. The down Arduino works similarly, in that it takes all incoming messages and processes them for relays, conductivity sensor, or video switcher. At a regular interval it will send a message containing conductivity sensor readings back up to the computer.



Systems Integration Diagram

PC Software

PC Software Flow Chart



The user interface for the software is run on a laptop and displays any errors that are affecting the controllers, the current outputs of all the motors and tools, the current control set and a list of possible interfaces. This year the software has two interfaces, first it has testing controls which allows it to run each part of the ROV separately. The second interface is called X-Controls and it mixes the motor outputs so that the pilot is able to drive the ROV without having to decide which motors to run individually.

Arduino

The two Arduinos used work together to run the ROV in the most efficient way possible. In an effort to minimize the cables needed, only one USB cable is connected to the computer, coming from the Arduino in the main box. This Arduino controls all the motor drivers on the surface, which runs power down the tether to the ROV, under the water. The Arduino also needed to run several relays for pneumatics, control a video switcher, and measure resistance on the conductivity sensor. Instead of running numerous cables down to do all this, the company decided to simply put an Arduino-nano along with the relays, video switcher, and other circuitry down with the ROV in a sealed container. However, because USB would lose the signal over the distance required, the software team decided to use ethernet which connects from the main control box Arduino to the one under the surface. Any commands intended for the down Arduino are first sent to the up Arduino which relays them on over ethernet. The down Arduino will also send messages back up, which first go through the up Arduino and then over USB to the computer.

QUALITY ASSURANCE

TROUBLESHOOTING TECHNIQUES

Troubleshooting is an important part of any building process and this year the company worked to refine the troubleshooting process -- making it highly efficient. The first step, as always, is to find a problem. Problems can occur in different components of the ROV, including the box, mission tools, and motors. The second step in the troubleshooting method is to use the company's test controls. This allows the team to individually test motors, payload tools and electrical connections. If the test control works then the team knows that there is no mechanical failure and that the problem may be electrical. Our electronics team then proceeds to test connections and look for loose wires and connections that could be causing the problem. If nothing appears wrong, the mechanical team searches the actual motor or tool for damage such as corrosion, denting, cracking, or bending. If this is the problem, the team fixes it and tests the system again. If no problem is found, the component would be replaced to ensure that all parts of the ROV are functioning properly.

CHALLENGE I: CAMERAS

The biggest challenge we faced concerning the cameras was our camera cases. We originally made all of our camera cases out of ABS plastic, but when we needed more, we decided to try making them from plaster powder. The plaster powder cases were neutrally buoyant, and were almost waterproof, unlike the ABS cases. When we tried to waterproof the plaster powder cases however, the epoxy holding the cases together reacted and the cases melted. We solved this problem by making all of the cases from ABS.

CHALLENGE II: DOWN ELECTRONICS

One of the major challenges that the company faced this year was fitting the electrical components into the waterproof capsule. The capsule had to fit the video switcher board, the arduino, and the relays. Although the arduino and the relays have a relatively short width, the board was 4 inches in length and 3 inches in width, not allowing it to fit into the tube. The board also has multiple ports and other components protruding from the face of the board that could be damaged if the board is ineptly squeezed in the pipe. In response, the team decided to make the board more compact by cutting off the excess area on the board that wasn't being used, and then cut it in half and folded it into a L shape. With this arrangement the capsule could fit the arduino into the open part of the L and the entire component could fit in the capsule. The capsule was then filled with mineral oil to prevent the exposed components from overheating because they were originally unable to function due to heat produced by the components. The mineral oil worked because it conducts heat better than air, which allowed it to draw the heat away from the components and disperse it in a non-harmful way.

Assembling the water-proof signal housing cap

Retrospective

Lessons Learned: Tech

Motor Mount – inches vs cm

The team has learned the importance of maintaining constant units throughout this project. This year the company designed several key components in CAD and then used the designs with a 3D printer and a CNC machine, or a similar method. This method of fabrication enabled the construction of much neater parts that would be smoothly cut and ultimately more precise. The tools taught the engineers that they needed to be very careful when specifying units. When making motor mounts, company members wrote all measurements in centimeters; however, the diagram was made using inches. When the piece was milled, it resembled a toilet seat more than a mount for our small motors. Fortunately, we tested the design on acrylic before mass producing the part.

Lessons Learned: Personal

This year the company learned how to organize the new members who wanted to be on the team. In past years, the company has either had so many team members that it could not function well, or has had so few members that it has not been an issue. This year the company tried several strategies to make sure there were just enough team members for a ranger team as well as a place for everyone to go. The first action taken was to make several teams: one ranger, two navigators, and one scout. This allowed people to pick what level they wanted to work at. The second strategy used was to carry over ranger team members from the year before and then invite people that wanted to join to move up while the others could stay in navigator to strengthen their skills. The company learned and accumulated these techniques over the course of the past few years as the program has grown, and now such methods were used to not only make a strong team for this year but to prepare new members to compete in the future.

Future Improvements

For the past few years the team has always been behind schedule at some point. In the future, we hope to keep our schedule accurately and not fall behind. On the mechanical side of things, we began using 3D printing to create camera cases, but we had some issues with the different materials. In the future we are hoping to use one type of material to create our components and hopefully have no mishaps as we did this year.

Reflection

After a team discussion, we all agreed that working together with fellow innovators was one of the most beneficial parts of ROV this year. In the beginning, we were all a little nervous about our capabilities. Nevertheless, after a short amount of time we became comfortable with each other and were able to express our ideas freely, without having to worry about being wrong. We have gained confidence in our opinions and are able to plan and carry out projects by ourselves without feeling lost. We all are confident in our soldering abilities as well as our abilities to use a drill, a band-saw and rivet gun. Our enthusiasm for science has greatly increased because we have had the experience of working together and building something new.

-Members of Aptos Mariners LLC

The Hammerhead Development Team

ACKNOWLEDGEMENTS

Thank you to all who assisted in making Aptos Mariner Robotics LLC successful.

- MATE Center -- For making this event possible
- Jill Zande and Matt Gardener -- For coordinating these events
- Aptos High School -- For the use of the AHS pool
- Joseph Manildi, Teacher Coach -- Hosting our lunchtime meetings
- Scott Randolph, Mentor -- Opening his house and sharing his electrical, software, and mechanical knowledge
- Keith Jeske, Mentor -- Teaching us how to handle power tools and sharing his mechanical knowledge
- Suzanne Randolph, Team Mom -- Having a warm dish or cold drink for the team
- David Patino – Numerically controlled manufacturing instructor
- Our Sponsors -- Whose donations made the construction of our ROV possible:
  Intuitive Surgical, Santa Cruz County Office of Education, the Johnson Family, and the Jeske Family.

REFERENCES

[1] Soleniod: http://www.automationdirect.com/adc/Shopping/Catalog/Pneumatic_Components/Pneumatic_Valves_-a-_Accessories/Solenoid_Air_Valves_-a-_Accessories/5-port_(4-way),_2-pos.,_Body_Ported_-z-_Manifold_(AVS-5,AM_Series)/AVS-5211-24D

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[3] Video Switches: http://www.mouser.com/ds/2/427/70058-240104.pdf

[4] Arduino: http://arduino.cc/en/Main/arduinoBoardUno

[5] Motor Controllers: http://www.pololu.com/product/755/

Appendix A: Development Schedule

	1-Oct to 18- Dec	18-Dec	18-Dec to 20-Jan	20-Jan to 27-Jan	27- Jan to 10-Feb	10-Feb to 10-Mar	10-Mar to 17- Mar	17-Mar to 22-Apr
Teach New Members to Use Electric Tools								
Practice Creating Structures Using Aluminum Angle								
Design and Build Camera Housings								
Competition Specs Released								
Begin Having Meetings Every Saturday								
Create the Mission Props								
Sketch and Design the Kraken								
Build Frame								
Solder Motors and Attach Housings								
Build Pneumatic Tools								
Attach Buoyancy								
Program Software								
Attach Pneumatic Tubing								
Have the ROV Water Ready								
Test ROV in the Water and Fix Any Bugs								
Add Ballast								

Appendix B: Check Lists

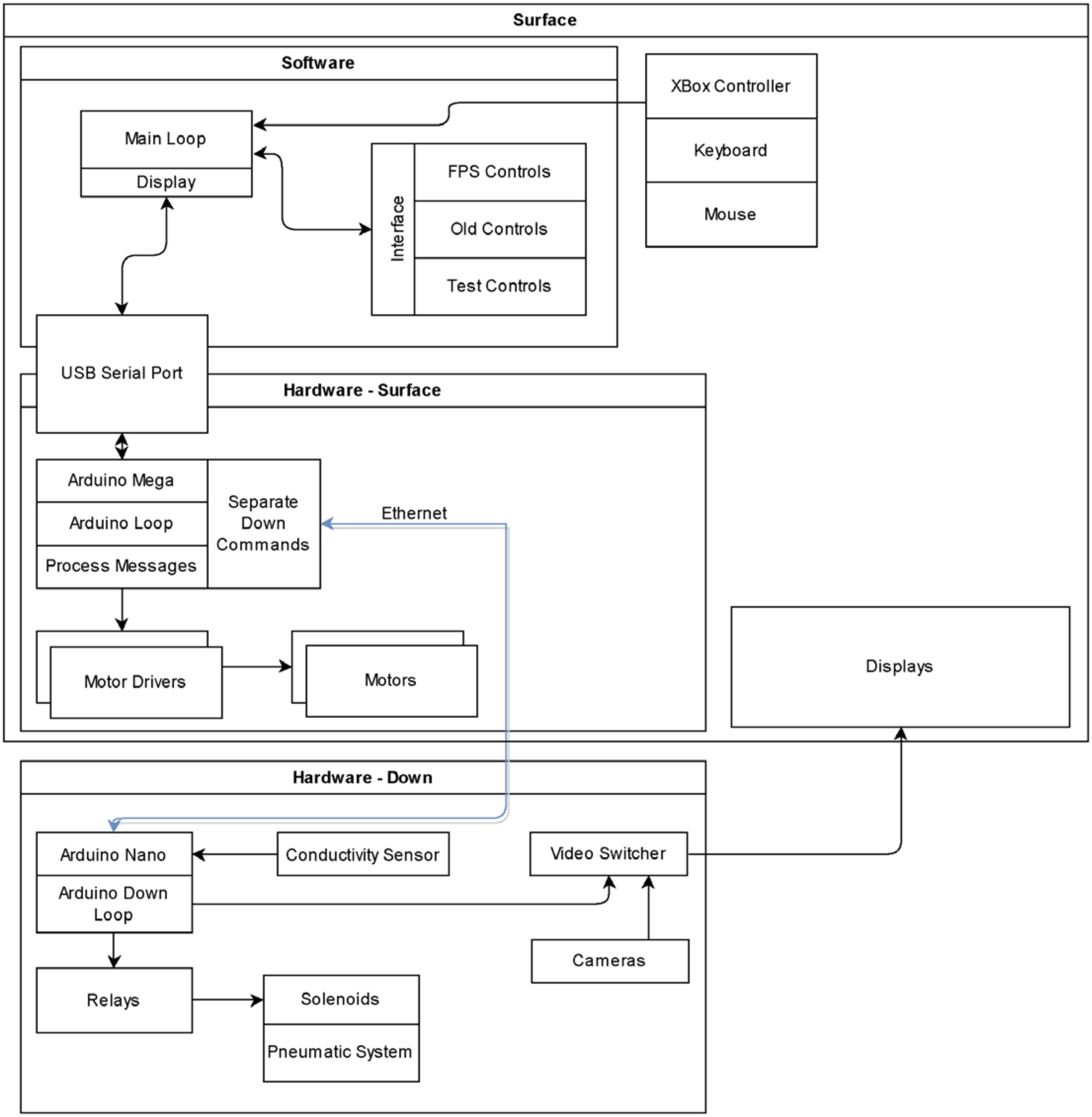
Safety Protocol

- ☐ Ensure all personnel have no loose hair and are wearing closed toed shoes
- ☐ Before working with the ROV, make sure there are no hazardous objects in the vicinity
- ☐ Ensure all electronics are far from the water
- ☐ Plug in the power from the source to the ROV tether's leads, if silent, proceed
- ☐ Before turning on the ROV, make sure all members are clear
- ☐ All members of the team must have proper communication
- ☐ Check that no wires are exposed
- ☐ Make sure the ROV is lifted so that active pistons will not hit the ground
- ☐ Make sure pneumatic pressure is lower than 40 psi before turning on compressor
- ☐ Ensure laser stops are deployed
- ☐ Before turning on control box, ensure that the box is plugged in correctly

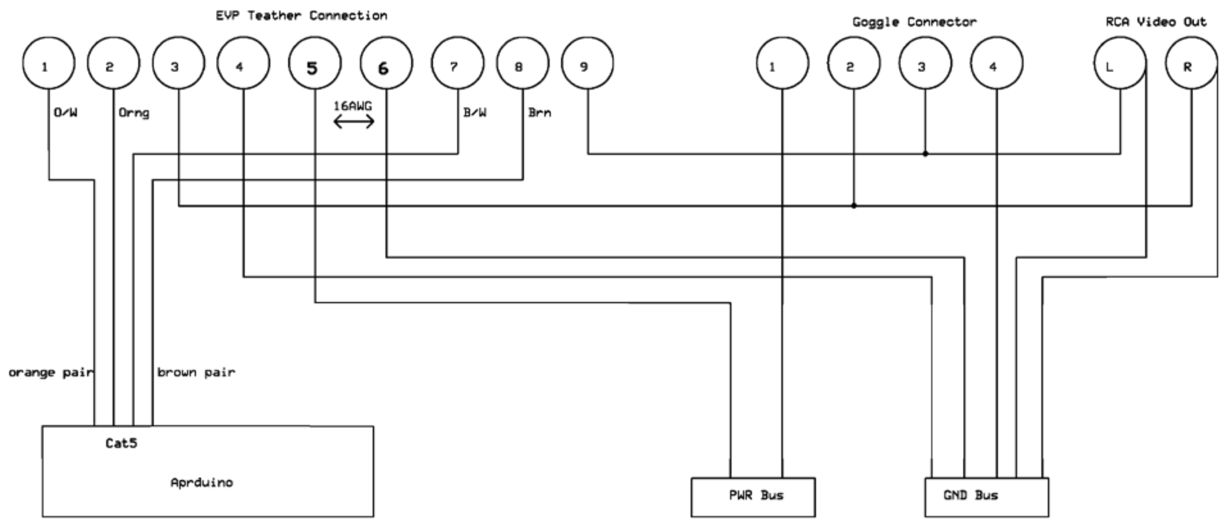
Tether Setup Protocol

- ☐ Make sure the control box will not be tugged when working with the tether
- ☐ Untangle the tether
- ☐ Coil the tether into a figure eight loop (have the ROV end on top)
- ☐ Check to make sure the floats are 1.5 meters apart

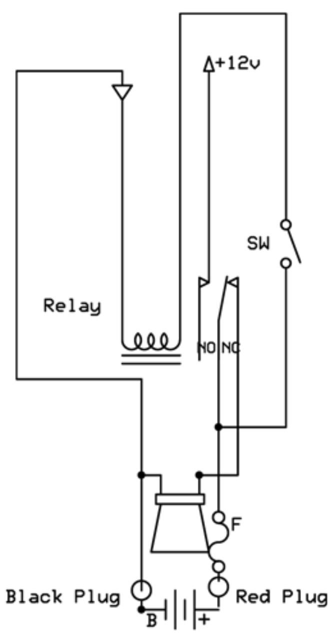
APPENDIX C: SYSTEM DIAGRAMS



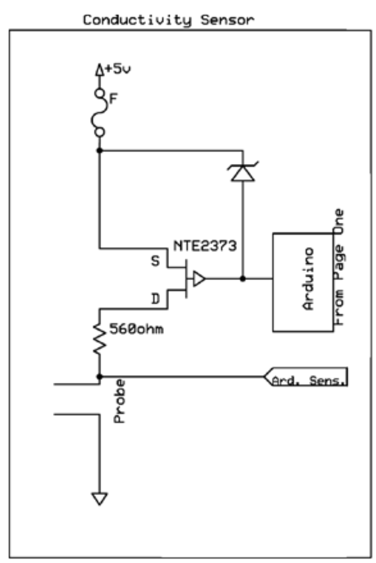
System Diagram



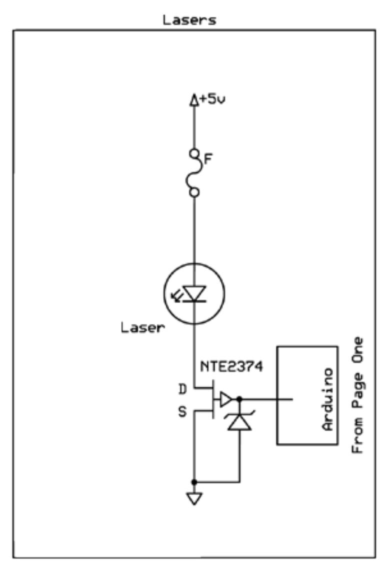
System Diagram



Power Protection and Warning System



Conductivity Sensor Control



Laser Power Control