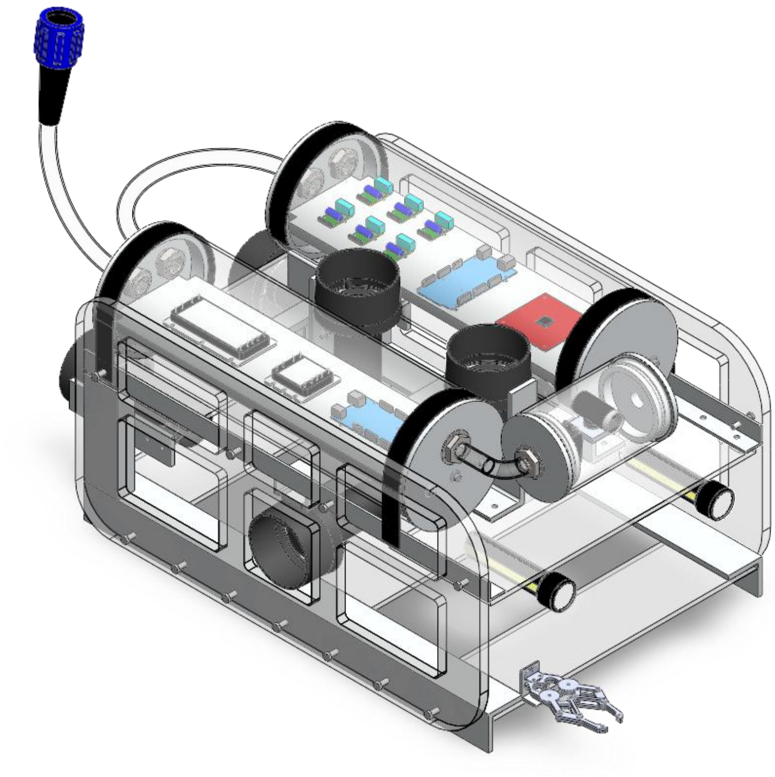


UNH AquaCats

University of New Hampshire(Durham, NH)

Team Members: Chris Barr (Chassis Engineer), Eric Boudreau (Computer Programmer), Ryan Cahill (Computer Engineer), Tyler Fausnacht (CTO), Nick Geist (CEO), Sean Gribbin (Propulsion Engineer), Alex Leboeuf (Tether Engineer), Sean Leighton (Computer Programmer/Pilot), Matt Sweeney (Propulsion Engineer)

Advisors:Dr. May-Win Thein, Dr. M. Robinson Swift

Abstract

The University of New Hampshire AquaCat team is an interdisciplinary company devoted to designing, manufacturing and testing underwater remotely operated vehicles. UNH AquaCat currently consists mechanical/design engineers, computer engineers, and computer programmers. Given the many disciplines incorporated in our company, we have three company subgroups; chassis, propulsion, and controls. The chassis engineering group is primarily responsible for the design and manufacturing of the ROV frame that will provide the vehicle with a rigid structure on which the electronics will be housed. With this responsibility comes maintaining a desired buoyancy of the vehicle and ensuring no onboard leaks occur during submersion.The propulsion engineering group is responsible for providing the ROV with maneuverability, allowing the vehicle to move with five degrees of freedom in the water at a speed and direction dictated by the pilot. The controls group is composed of a computer engineer and computer programmers. They together are responsible for power distribution onboard the ROV, writing software to control the vehicle and determining the necessary electronic hardware components to do so.

This project provides an opportunity for our company to apply our knowledge of engineering, including fluid dynamics, systems and controls, finite element analysis, machining, and computer science.

Table of Contents

Photographs of ROV

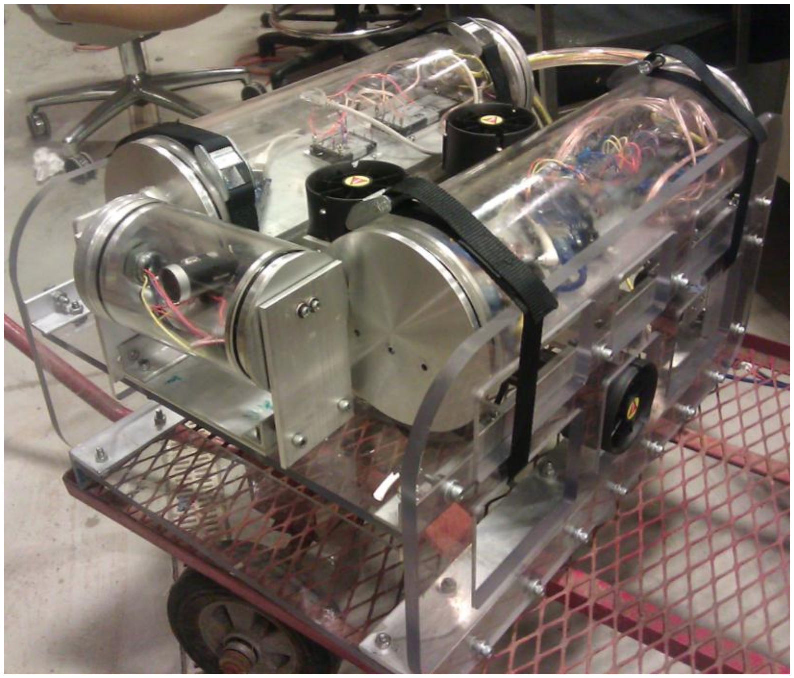


Figure 1: Completed ROV undergoing control scheme testing.

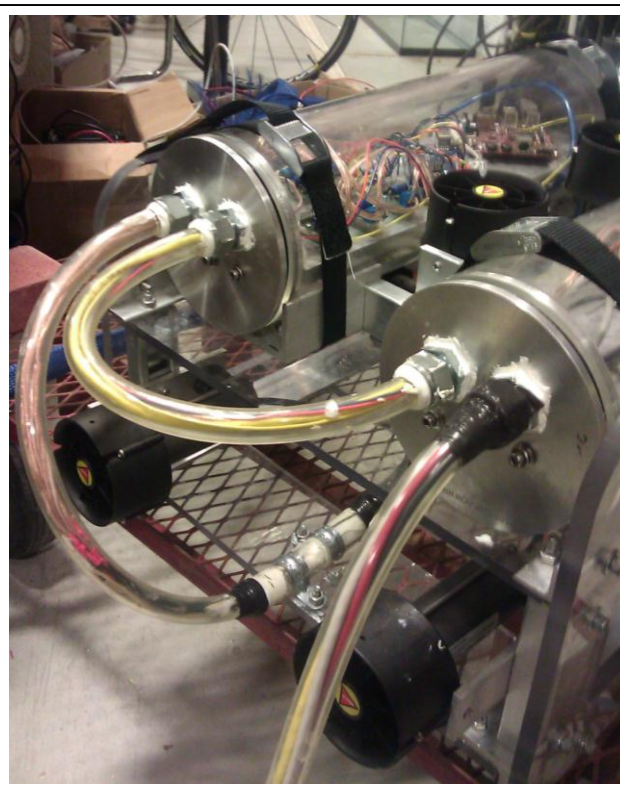


Figure 2: Rear of the ROV, showing the various tube connections.

Expense Sheet

Date	Description	Amount
10/25/2013	Optically Clear Cast Acrylic Tube, 6" OD X 5-1/2" ID, 5' Length	$ 294.04
11/5/2013	Seabotix BTD150 Thrusters	$ 1,408.92
11/20/2013	Optically Clear Cast Acrylic Tube, 4" OD X 3-3/4" ID, 1' Length 6061 Aluminum, 90 Degree Angle, 1/8" Thick, 1" X 1" Legs, 8' Length	$ 64.95
11/20/2013	Optically Colored Cast Acrylic Sheet, 1/4" Thick, 12" X 24", Blue	$ 43.77
1/7/2014	Impact-Resistant Polycarbonate Sheet, 1/2" Thick, 12" X 24", Clear	$ 116.28
1/14/2014	Multipurpose 6061 Aluminum, 90 Degree Angle, 1/4" Thick, 2" X 2" Legs, 4' Length Multipurpose 6061 Aluminum, 1/4" Thick, 1-1/2" Width, 3' Length	$ 54.92
1/16/2014	Multipurpose 6061 Aluminum, 6" Diameter, 1" Long x4 Buna-N O-Ring, AS568A Dash Number 429, packs of 5	$ 105.72
1/17/2014	Agar Powder	$ 15.95
1/18/2014	Microsoft LifeCam Cinema 720p HD Webcam for Business - Black	$ 35.86
1/24/2014	Impact-Resistant Polycarbonate Sheet, UV-Resistant, 1/4" Thick, 24" X 24", Clear Multipurpose 6061 Aluminum, 4" Diameter, 6" Long	$ 97.80
1/24/2014	#755 Pololu High-Power Motor Driver 18v15 (H-bridge)	$ 209.70
1/24/2014	Traxxas 2075 Digital High Waterproof Torque Servo TRA2075	$ 39.96
1/28/2014	Type 316 Stainless Steel Hex Nut, 1/4"-28 Thread Size, 7/16" Width, 7/32" Height, packs of 50 Optically Clear Cast Acrylic Tube, 6" OD X 5-1/2" ID, 3' Length Zinc-Plated Alloy Steel Socket Head Cap Screw, 1/4"-28 Thread, 1" Length, packs of 25	$ 187.23
1/28/2014	Amazon Supplies	$ 48.17
2/3/2014	Impact-Resistant Polycarbonate Round Tube, 6" OD, 5-3/4" ID, Clear, 4' Length	$ 129.44
2/4/2014	SEN-10736 - 9 Degrees of Freedom - Razor IMU	$ 124.95
2/4/2014	Butt Splice, Nylon-Insulated Moisture-Resistant, 16-14 AWG, Packs of 10 Solid Wire, 300V AC, 18 Gauge, 25 ft: Red, Yellow, Blue, Green, White & Black	$ 60.47
2/6/2014	Voltage Converters 48V/18.5V 200W 48V/5V 50W	$ 281.49
2/11/2014	MATE Registration	$ 100.00
2/17/2014	Buna-N O-Ring, AS568A Dash Number 160, Packs of 25 2 7475T42 Economy Wraparound Safety Glasses, Clear Lens, Clear Frame, Black Nylon Arms	$ 22.96
2/20/2014	8GB Micro SD, 7ft CAT5E Cable, 4PORT USB HUB	$ 59.97
2/24/2014	ROB-11524 - Robotic Claw - MKII ROB-11674 - Robotic Claw Pan/Tilt Bracket - MKII ROB-10333 - Servo - Generic Metal Gear (Micro Size)	$ 60.87
2/24/2014	Impact-Resistant Polycarbonate Sheet, 3/8" Thick, 12" X 24", Clear Zinc-Plated Alloy Steel Socket Head Cap Screw, 1/4"-28 Thread, 1-1/4" Length, Packs of 25 Type 316 Stainless Steel Hex Nut, 1/4"-28 Thread Size, 7/16" Width, 7/32" Height, Packs of 50 316SS Pan Head Phillips Screw for Sheet Metal, No. 6 Size, 3/4" Length, Packs of 100 Commercial Grade Pipe Thread Sealant Tape, 16 yd L X 1/2" W, .0028" Thickness, 0.5 G/CC Density Steel Strut Channel, Solid, 13/16" X 1-5/8", Zinc-Plated, 4' Length Low-Pressure Aluminum Threaded Pipe Fitting, 3/4 Pipe Size, Cross	$ 185.73
3/3/2014	SEN-10167 - Humidity and Temperature Sensor - RHT03	$ 33.78
3/5/2014	32ft 10M USB 2.0 A Male to A Female Active Extension / Repeater Cable	$ 30.19
3/5/2014	USB Waterproof Cable - WPA Extension	$ 19.00
3/5/2014	L-Bracket Steel Yor-Lok Tube Fitting, Through-Wall Straight Connector for 3/4" Tube OD U-Channel	$ 272.66
3/21/2014	Multipurpose 6061 Aluminum, Rectangular Bar, 1/4" X 1-1/2", 2' Long Impact-Resistant Polycarbonate Sheet, 3/8" Thick, 12" X 24", Clear	$ 57.25
3/24/2014	Nylon 6/6 Male-Female Threaded Hex Standoff, 3/16" Hex, 3/16" Length, 4-40 Screw Size, packs of 5 Zinc-Plated Steel Pan Head Phillips Machine Screw, 4-40 Thread, 1/4" Length, packs of 100 U-Channel Made with Teflon PTFE 1/2" Base X 9/16" Legs, 1/16" Wall Thickness, 2 ft. Length Zinc-Plated Alloy Steel Socket Head Cap Screw, 8-32 Thread, 1" Length, packs of 50	$ 104.24

4/3/2014	Low Profile Waterproof A Extension - RR-116320-06-39 USB Waterproof Mountable Cable - Low Profile - RR-116310-05-39	$ 29.40
4/3/2014	Vehicle Wire, 10 Gauge, 100 ft Spool, Black Solid Wire, 300V AC, 22 Gauge, 25 ft, Green Solid Wire, 300V AC, 22 Gauge, 25 ft, Blue Solid Wire, 300V AC, 22 Gauge, 25 ft, Orange Super-Performance Cobalt Steel Spiral Point Tap, 4-40 Dow Corning High-Vacuum Grease, 5.3-Ounce Tube Anchorlube Cutting and Tapping Fluid, Water-Based, 4-Ounce Container Solid Wire, 300V AC, 22 Gauge, 25 ft, Purple Solid Wire, 300V AC, 22 Gauge, 25 ft, Yellow Super-Performance Cobalt Steel Spiral Point Tap, 10-24	$ 130.15
4/3/2014	Vehicle Wire, 10 Gauge, 100 ft Spool, Red	$ 42.91
4/7/2014	Tap Wrench, Sliding T-Handle, 0-1/4" (1.6-6.3MM) Tap Size Type 316 Stainless Steel Socket Head Cap Screw, 10-24 Thread, 1" Length, Packs of 25 Pressure-Sealing Washer for Screws & Bolts, No. 10 Screw Size, .45" OD, .04"-.06" Thickness, Packs of 10 18-8 Stainless Steel Truss Head Phillips Machine Screw, 4-40 Thread, 3/8" Length, Packs of 100	$ 42.84
4/9/2014	Tether Sleeve	$ 78.30
4/14/2014	Sealant	$ 13.89
4/15/2014	Nylon 6/6 Male-Female Threaded Hex Standoff, 3/16" Hex, 5/16" Length, 4-40 Screw Size, Packs of 5	$ 63.28
4/15/2014	Buna-N O-Ring, AS568A Dash Number 117, Packs of 100 Buna-N O-Ring, AS568A Dash Number 237, Packs of 50 Water-Resistant Clear Polyurethane Tubing 3/4" ID, 1" OD, 1/8" Wall Thickness, 2 ft. Length	$ 26.60
4/15/2014	FTDI Basic Breakout - 3.3V	$ 19.95
4/15/2014	High-Strength 3M Marine Sealant, 3-Ounce Tube, Number 5200, Fast Hardening	$ 22.10
4/15/2014	Lashing	$ 15.94
4/17/2014	High-Strength 3M Marine Sealant, 3-Ounce Tube, Number 5200, Fast Hardening Multipurpose 6061 Aluminum, 3/16" Thick, 3" Width, 3' Length Butt Splice, Vinyl Insulated, 12-10 AWG, Packs of 50	$ 66.11
4/28/2014	Pressure-Sealing Washer for Screws & Bolts, No. 10 Screw Size, .45" OD, .04"-.06" Thickness, Packs of 10 Steel Yor-Lok Tube Fitting, Straight Adapter for 3/4" Tube OD X 3/4 NPT Male	$ 37.62
4/29/2014	Steel Yor-Lok Tube Fitting, Through-Wall Straight Connector for 3/4" Tube OD	$ 32.57
5/21/2014	USB to Ethernet converters, misc items	$ 230.42
5/21/2014	Sealant Tape, Electrical Tape, misc items	$ 43.36
	Total Expenses (as of 5/29/2014)	$ 5,161.71

Income	
Balance from 2012-2013	$ 287.64
Parent's Association Grant	$ 4,000.00
Dean's Office Grant	$ 2,000.00
NH Sea Grant	$ 2,000.00
ME Office Grant	$ 1,200.00
Individual Donations	$ 980.00
Axis New England Donation	$ 250.00
Total	$ 10,717.64

Donations		
Description	Donor	Estimated Cost
Arduino Mega (x2)	UNH ECE Department	$ 40.00
Beagleboard XM	UNH ECE Department	$ 150.00
Electronics Tubes End Cap Machining	Portsmouth Naval Shipyard/Turbocam	$ 200.00

System Interconnection Diagram (SID)

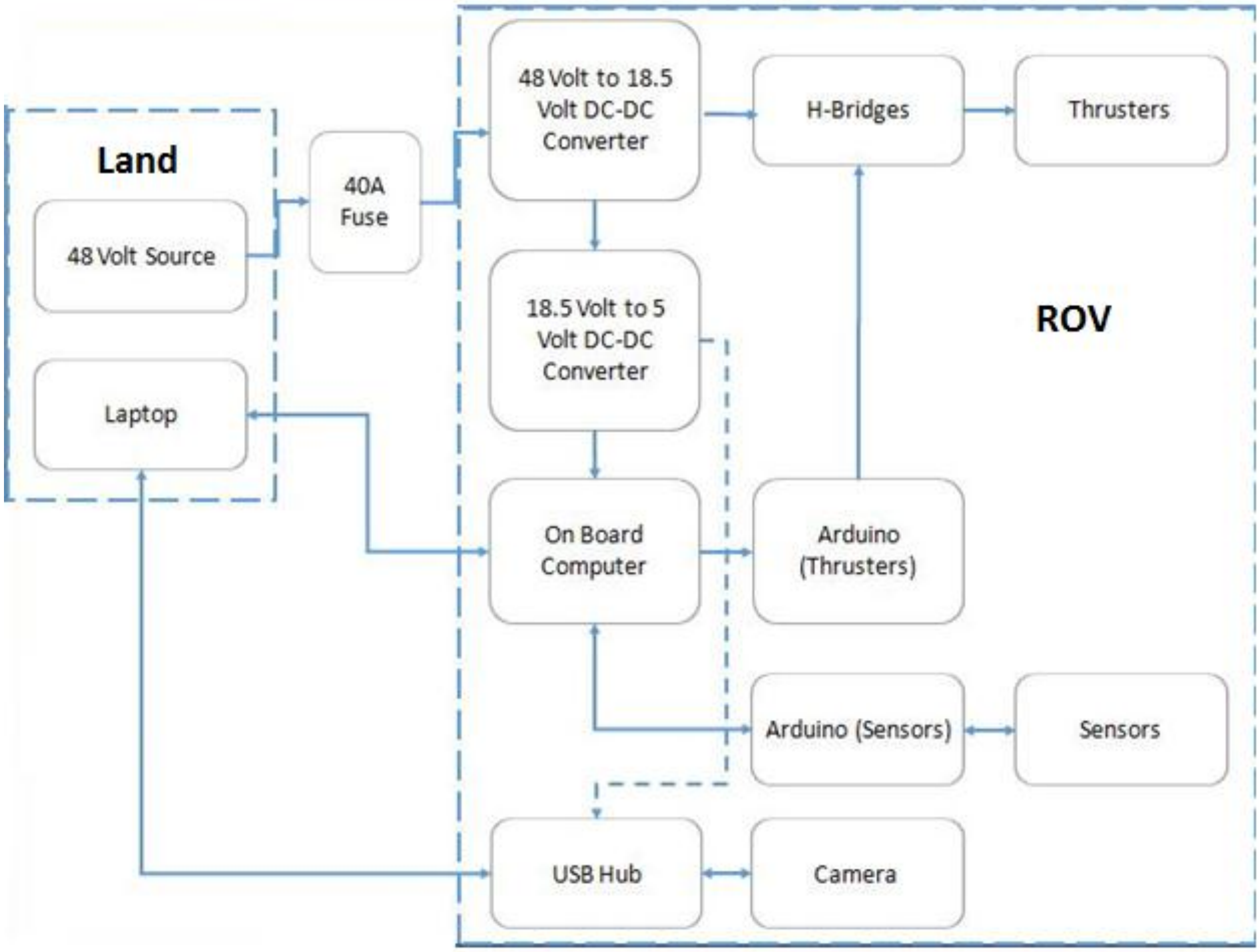
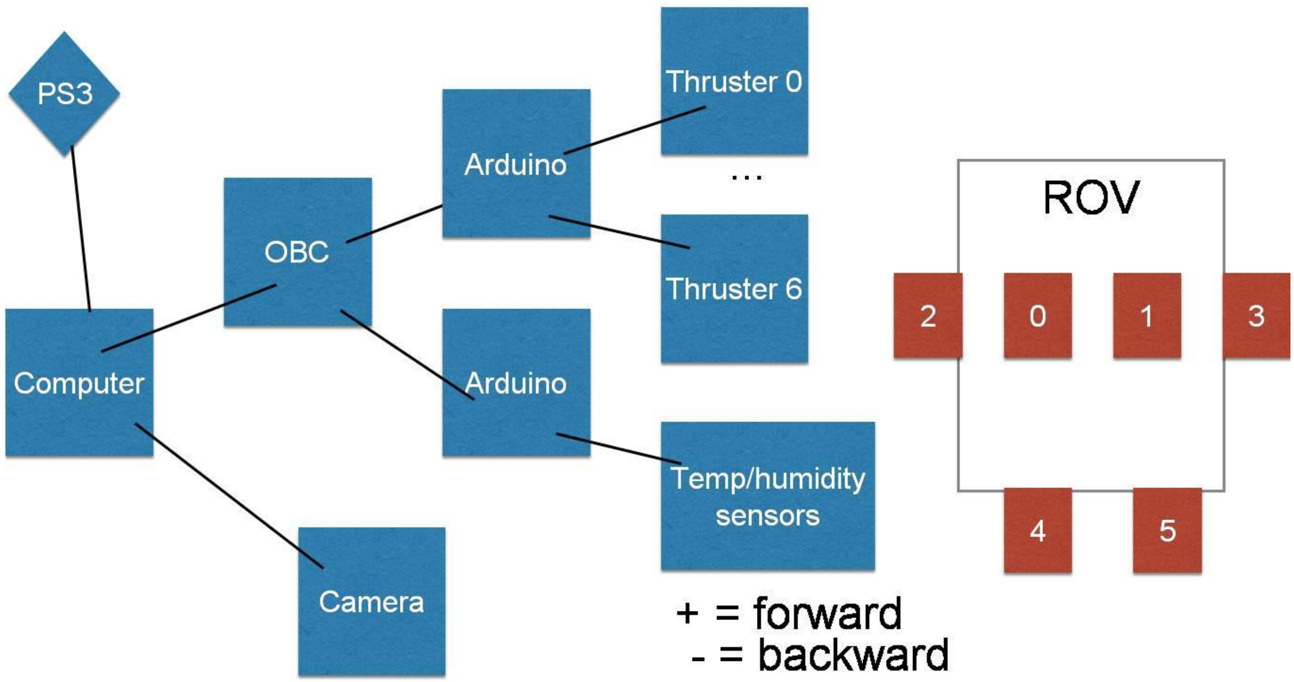


Figure 3: SID showing distinction and interconnectivity between land and water components.

Software Flow-Chart



Button	T0	T1	T2	T3	T4	T5
X	+	+				
O			+	+		
^					+	+
▯					+	-

Figure 4: Software flow chart showing logic that allows the ROV to perform basic functions.

Design Rationale

The chassis subgroup drew inspiration from past ROVs as well as commercial ROVs while adapting these designs to fit both the mission tasks of the MATE competition and the PhD research requirements. The responsibilities of the chassis subgroup are to design and construct the ROVs frame and buoyancy system. The 2013-2014 ROV was designed to fulfill the competition requirements while maintaining a degree of simplicity. The ROV chassis main goal was to minimize size. Size proved to be a problem in last year's ROV and the MATE competition this year has a solid size requirement having to fit through a 75cmx75cm square hole. The chassis also wanted to keep slight positive buoyancy as a failsafe in case of electronic failure during testing. Symmetry was pivotal in the design of the frame. By keeping the ROV as symmetrical as possible, the center of mass and buoyancy stay close to the center of the vehicle, which is ideal for maneuverability. The chassis team is also in charge of waterproofing electronics and mounting the tether to the ROV keeping the tether relieved of strain for safety purposes.

The chassis of the ROV is designed to be rigid while maintaining a fairly lightweight structure. The dimensions of the frame were designed to be 30.5 cm tall, 45.7 cm wide and 61 cm long. This will provide plenty of space for the vehicle to fit through the 75cmx75cm hole. The chassis can be divided in the mainframe, electronics tubes, and tether.

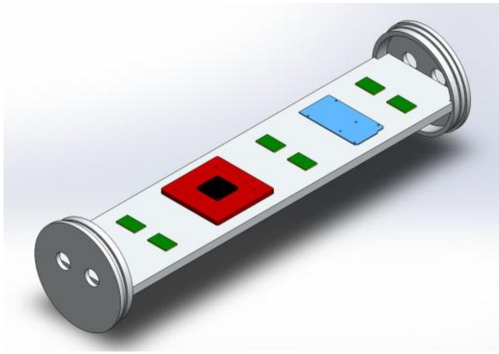
The mainframe is composed of mostly polycarbonate plastic, which makes up the main side plates and all of the cross braces and shelves inside the ROV. Polycarbonate was chosen due to its structural rigidity and ability to be machined. In addition, it has a density close to that of water which will help the neutral buoyancy. The mainframe also has aluminum angle, which provides extra rigidity to the structure while also allowing the pieces of polycarbonate to be connected more easily.

The electronics tubes are made out of acrylic. This material was chosen mostly for its ability to maintain shape during machining and also for its clarity. A 6" diameter acrylic tube was chosen based on what has worked in past years, but it was decided this year to go with a 1/4" wall thickness as opposed to a 1/8" wall thickness used on previous ROVs. It is believed that the thicker walled tube will give the ROV some more strength, as eliminating gross weight was not considered a priority in the design of the tubes. The end caps of the tube are made from cylindrical aluminum stock on a lathe. The end caps all have a standard O-ring groove in them to allow for a tighter, waterproof seal on the tubes. Some of the tubes have holes drilled into them in order to fit steel Yor-Lok fittings, which were chosen to accommodate the flexible polyurethane tubing that the wires run through for thruster, power, USB, and Ethernet. The caps also have a countersink drilled into them, and a small O-ring is fit onto the Yor-Lok fitting to achieve a tighter seal. The extra precautions for waterproofing are most important on the tubes due to the sensitivity of the electronics.

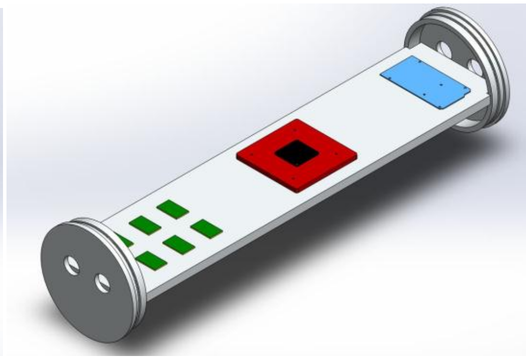
The tether is the connection between the operators on land and the vehicle in the water. The tether consists of power cables, anEthernet cable for the camera feed and a second Ethernet cable for communication with the on-board computer. Because it serves such a crucial purpose to the operation of the vehicle, there are a few design parameters that must be considered. One characteristic that has to be considered is the neutral buoyancy of the tether. If the tether weighs down the vehicle it will severely prohibit the maneuverability and therefore a neutrally buoyant tether is the goal for design. The tether must also be flexible for the same reason. The way that these two goals are met is by using a flexible sheath that covers the cables while providing minimal drag and downward force. Another design goal for the tether is to ensure that there is minimal strain on the cables running from the vehicle to land as a broken cable will sever communication and cause a failed mission. In order to minimize strain the connection to the ROV must be covered with tubing so that there is no stress concentration as the cables enter the tube.

To fully complete the design of the frame several forms of initial analysis were conducted in order to fine tune the design of the chassis before production. In order to gain a further understanding of the balance of mass and buoyancy, a full set of mass and buoyancy calculations were completed to gain an understanding for what weight need to be added or subtracted to gain a very slight positive buoyancy and meet the objective for the design of the chassis.

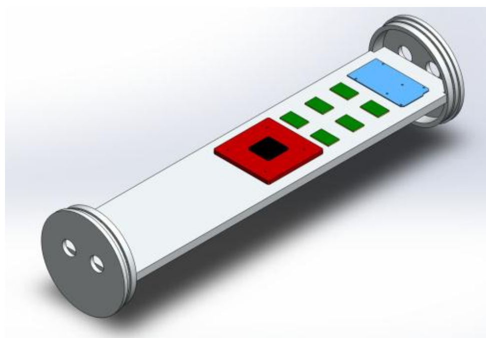
In conjunction with the controls team, a Finite Element Analysis simulation was completed on the electronics tubes to help design the layout of the electronics in the tubes. Several design options were chosen to analyze and determine which design has the most benefit as far as heat transfer and temperature distribution. The three candidate designs shown below in Figure 2 represent the possible layouts of the electronics inside the tubes.



Configuration 1



Configuration 2



Configuration 3

Figure 5: Electronics configurations simulated using SolidWorks thermal FEA.

After conducting FEA on all three of the candidate designs, it was determined that configuration 2 is the most effective configuration to decrease high temperature zones while also leaving ample room for wire management. Final temperature and heat flux distributions are shown in the Appendix. During the analysis, the models of the electronics had to be simplified to run the simulation and the heat power coming from the electronics was not an exact value and it is uncertain how much power produces heat. These estimations would affect exact thermal analysis but for the purposes of this study, the comparison of designs was still effective.

This year, the propulsion team decided to use six thrusters in the design of their propulsion system; two for each of the three translational degree of freedom (see Figure 6).

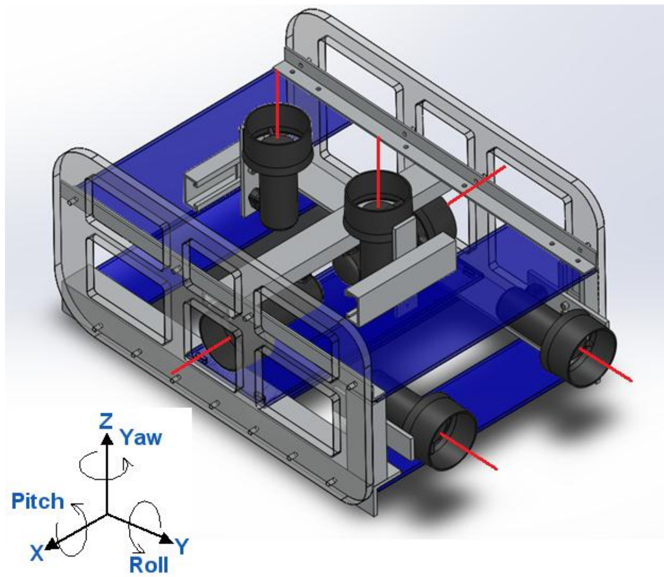


Figure 6: A diagram of the ROV frame with red lines to represent all possible directions of thrust.

During the preliminary decision making process regarding the thruster scheme, previous year's designs were analyzed and taken into consideration. The team saw a serious flaw in last year's propulsion system which included only four thrusters, two for vertical motion and two for forward-backward motion. Our team saw this scheme as hindering to the overall maneuverability of vehicle as it neglected the third translational degree of freedom. With that in mind, it was deemed that all three translational degrees of freedom were desired for our ROV in order to achieve a higher level of motion control and the six thruster design was decided upon. Referring again to Figure 3, it should also be noted that the thruster configuration allows for two rotational degrees of freedom; pitch and yaw. The staggered positioning of the vertically oriented thrusters about the y-component of the ROV's center of mass allows for pitch rotation and the staggered positioning of the forward-backward oriented thrusters about the x-component of center of mass allows for yaw rotation. The two lateral thrusters, producing thrust along the x-axis, were deliberately positioned collinearly so that roll rotation could be eliminated. Typically, ROVs remain positioned upright in the water and roll rotation is generally avoided altogether. So, by positioning these two thrusters collinearly, roll was eliminated and an effective and comfortable five degrees of freedom were achieved for the ROV.

As far as deciding which type of thrusters to use for the propulsion system a few factors came into play. To us, there appeared only two options: make our own thrusters or purchase commercially available ones. Again obtaining advice from our advisors and their knowledge of how previous teams had gone about the same process, we had decided to purchase commercially available thrusters. This decision was based upon hardships experienced by a previous team who had painstakingly attempted to design, fabricate, and waterproof their own thrusters. In an attempt to gain some piece of mind about the reliability of our thrusters we decided to go with the BTD 150 thruster from the trustworthy ROV manufacturer, SeaBotix Inc. The decision to go with the BTD 150 thruster was also strongly influenced by the previous year's team who had initially selected the thruster for their vehicle.

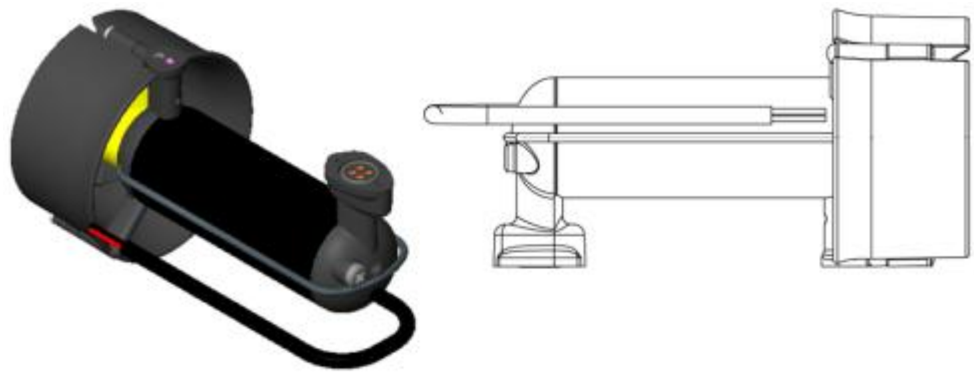


Figure 7: Computer-aided design model rendering and drawing of Seabotix BTD 150thruster[1].

The controls group is tasked with writing the software that controls the ROV and extracts data from the ROV. In writing this software, the team hoped to make controlling the ROV quick and effective. The software should be robust but also easy for the operator to use. It should respond to user input quickly and return data from the ROV in a timely manner. It should be written in a clean manner to ensure that others who read the source can understand how it works and modify it easily. It should be able to deal with issues that may arise and either handle the situation or alert the operator. Overall, the goal for the software was to make it functionally robust and easy to operate.

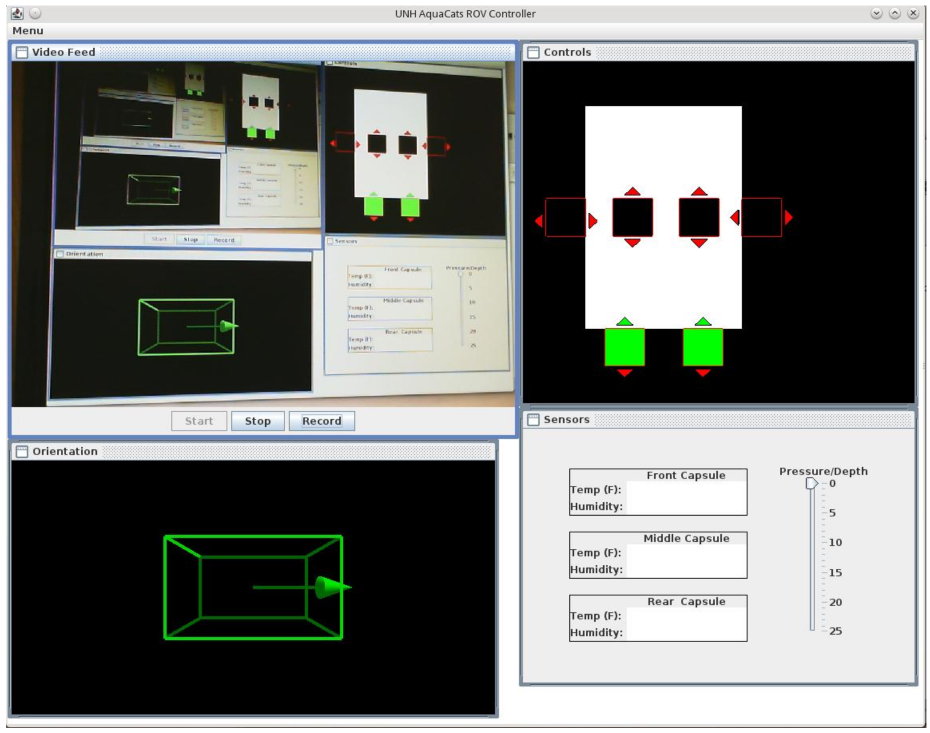


Figure 8: Screenshot of GUI display

One of the software components for this project is the GUI that is run from the laptop by the operator. The GUI is written in Java, which allowed the team to create and modify the program quickly and with relative ease. This also allows it to be run on multiple platforms with little effort. The GUI connects to the on-board computer using TCP sockets over an Ethernet connection to send and receive data. This allows the team to send and receive data to easily leveraging existing protocols. A picture of the GUI and its components can be seen in Figure 7 and each component is described below that.

This GUI performs several tasks for the team. It interprets commands from a connected PS3 (Playstation 3) controller and uses the input to control thrusters on the ROV. The face buttons are used to select which thrusters are powered, the analog stick controls the amount of power the selected thrusters should receive, and a shoulder button allows the direction to be changed. On top of this, a panel on the GUI shows which thrusters are activated and the direction in which those thrusters are running. This allows the operator to easily see what thrusters the GUI is telling the ROV to activate.

The rest of the functionality revolves around reading data from the ROV. A sensor panel displays sensor data read from the ROV. The temperature and humidity readings are taken from 3 of the tubes on the ROV. These allow the operator to see whether the tubes are within safe temperature and humidity levels. The background color will even turn red behind the readings when readings start to go too high. Pressure is also read to give the operator an idea of how far below the water the ROV is.

An orientation panel exists to show how the ROV is positioned in the water. A rectangle representing the ROV is shown in this panel, and rotates based on the roll, pitch, and yaw data received from an IMU device on-board; which has 9 DOF.

The other panel that exists is the video feed panel. This panel allows the user to see the video feed from the on-board web-cam so that the operator can navigate the ROV. Buttons exist to start and stop the video feed as the operator desires. This was done so that the GUI doesn't have to initiate the video device right away; rather the operator can initiate the device and start the video feed when they are ready. Recording functionality also exists, when the button is pressed, the GUI starts saving video frames; when the button is pressed again, the recording stops, and a video file is available for future viewing. One thing to note is that the camera's USB cord is run up through the tether directly (via ethernet) meaning the video feed is not routed through the on-board computer.

The on-board computer, the BeagleBoard-xM, was tasked with two tasks. Receiving thruster commands from the GUI and sending it to an Arduino tasked with controlling thrusters, and receiving sensor data from a sensor Arduino and the IMU to push up to the GUI. To do this, the code on the on-board computer was divided into 3 server programs. One for the motor data, one for the temperature, humidity, and pressure data, and one dedicated to the IMU data.

The motor server is tasked with receiving thruster commands from the GUI and passing them along to the attached Arduino. It receives three components; an index indicating what thrusters to power, the direction to run the thrusters in, and the speed at which to run the thrusters at. The server does check to ensure that the data is valid before passing it to the Arduino, invalid data is ignored.

The sensor server receives data from the Arduino and passes it along to the GUI. This data consists of temperature, humidity, and pressure data. No error checking is necessary in this case as the Arduino and GUI code check over the data; meaning this server acts as a deliverer and nothing more.

The IMU server acts similarly to the sensor server, except that it receives data directly from the IMU, which is connected to the on-board computer using a breakout USB adapter rather than through an Arduino. The data is received in the form of roll, pitch, and yaw and is sent to the GUI without any modification.

As mentioned briefly above, there is also software loaded onto the Arduino prototyping boards. There are two Arduino boards on the ROV; one for activating thrusters and eventually servos for the camera and arm, and the other for reading data from sensors.

The motor Arduino parses the input it receives from the on-board computer to determine the thrusters it needs to change, the direction they should run in, and the speed at which they should spin. Eventually it will also be able to read commands for activating servos for the camera and the mechanical arm.

The sensor Arduino is responsible for reading data from the various sensors that are attached to it and relaying this data back to the on-board computer. The sensors attached include combo temperature/humidity sensors, one for each tube; and a pressure sensor for gaging water pressure. Due to the specifications of the combo temperature/humidity sensors, the sensor data is only polled once every 2 seconds, but this is sufficient for this kind of data.

The entire controls scheme as far as power management goes relies on the amount of power we will be receiving at the MATE competition. The source is 48 volts DC from the surface which will be carried down through the tether and distributed as necessary. The highest voltage requirement of the entire control scheme is 19 volts DC which is needed for the H-bridges. For this reason the voltage is dropped down to 18.5 volts DC immediately after it reaches the first electronics tube of the ROV. The decision to go from 48 to 18.5 volts DC was made based on the wide range of 48 volt DC power converters that could be found. The output voltage of 18.5 volts DC was chosen because it was the highest that didn't go above the limit of 19 volts DC for the H-bridges. An image of the 48 to 18.5 volt DC converter is shown in Figure 8.

Figure 9: The 48 to 18.5 volt DC converter chosen for the vehicle

The output of the 48 to 18.5 volt DC converter splits three ways. The first very crucial way is feedback into pins on the converter itself. This ensures that the converter is consistently putting out 18.5 volts DC under constantly changing voltage demands. Second, 18.5 volts DC will be

Figure 10: The 18.5 to 5 volt DC converter chosen for the vehicle

sent to a voltage converter which will further step down the voltage to 5 volts DC. The sole purpose of this voltage converter is to send power to the on-board computer. A cable which would fit into the 5 volt input of the on-board computer was spliced on the output of this second DC converter to send the computer the power it required. The 18.5 volt DC to 5 volt DC power converter is shown in Figure 9.

The third and final way that the voltage splits from the 48 to 18.5 volt DC power converter is to power the positive and negative voltage inputs of the six H-bridges, one of which can be seen in Figure 10.

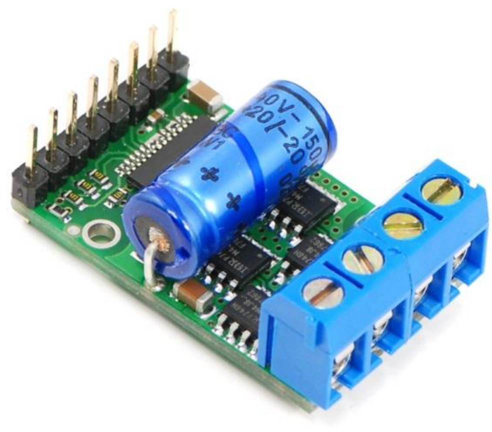


Figure 11: An image of the H-bridge used to power the thrusters

The H-bridges are needed because the Arduino will not be able to power the thrusters by itself. Although the Arduino can send the correct pulse width modulated and directional signals, it can only send a maximum of five volts. The H-bridges mix the higher voltage coming from the converter with the pulse width and directional signals from the Arduino and basically create the same signals, just with a higher amount of power. The two outputs of the H-bridges run directly to the thrusters to power them.

Although the servos for the camera housing and movable arm have not been mounted and tested yet, they will likely be powered by the 5 volt DC converter. The Arduino can supply the necessary five volts for one servo but unfortunately more than that will be required for the project. Just a single servo even draws a considerable amount of power and the Arduino may not be able to handle that kind of strain. As there is only one connection on the 5 volt converter, it will be able to handle the occasional draw from the servos.

Safety

In order to maintain safety within the workplace, AquaCat requires its employees to follow safety rules. Eye and ear protection as well as long pants and close-toed shoes are required when working in the shop using heavy machinery. When testing the ROV in the water, all employees are required to wear life preservers. Before placing the ROV in the water, there are several safety checks made in order to prevent a hazard. These measures include but are not limited to fastening each bolt on the vehicle, ensuring waterproof seals are intact, all electrical connections are not exposed, and that components are firmly attached to the frame.

Figure 12: Employees demonstrating safe machining techniques

Challenges

The most difficult and persistent challenge that faced AquaCat during the production of the ROV was waterproofing. In an attempt to fight against water penetration, precautionary effortswere taken by using O-rings on the end caps for both of the electronics tubes and the camera housing. O-rings used along with marine grease create a very tight seal around the tubes. In order to keep the caps tight to the tube and provide an extra seal, the aluminum plates inside the electronics tubes are attached to the end caps by 3 screws which grab onto tapped holes in the electronics plates and pull the caps toward each other on the tubes. In order to waterproof the connections into the electronics tubes, 3M epoxy resin was used on the yor-lok

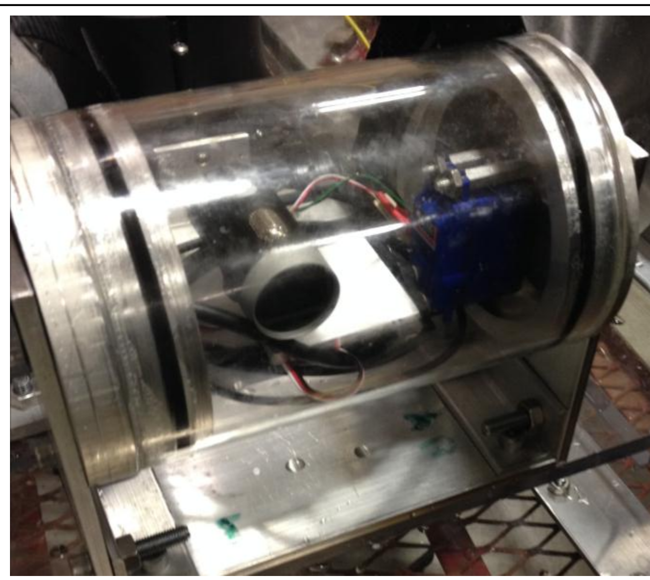
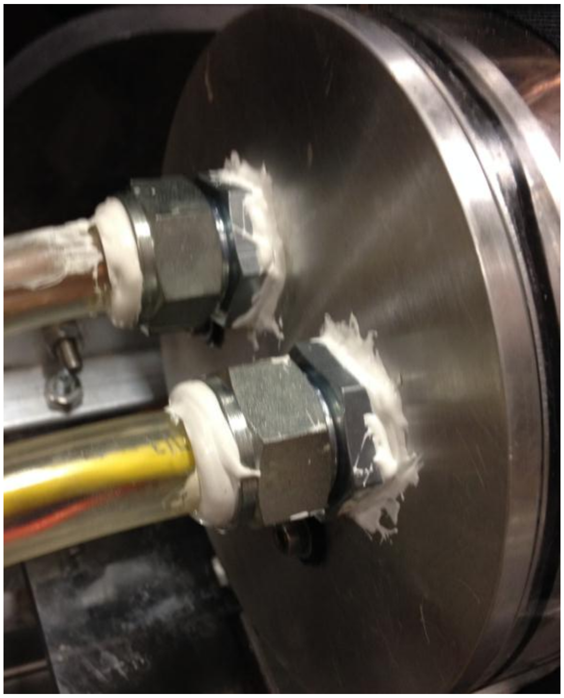


Figure 13: O-rings and marine grease were used to seal the end caps of the various electronics tubes.

fittings to ensure a clean seal around the connection. The tether is crucial to a functioning ROV and needed to be waterproofed just as well as the rest of the ROV. The two power cables of the tether were waterproofed using a Bulgin 900 series buccaneer connection as well as some marine epoxy on the ends to ensure a good seal. The Ethernet cables use a buccaneer connection which was epoxied on the ends of the connection to ensure that no water will get into the ROV.



Figures 14: Marine epoxy was to ensure a seal around the Yor-Lok compression fittings for both the electronics tubes and camera housing.

Even after taking these precautionary measures, leaks persisted within the electronics tubes and tether upon initial submersion. After removing water that had entered the tubes during submersion and identifying where the leaks had occurred, the team of engineers added additional epoxy to said locations on the ROV and continued with submersion tests to again check for water entry.

This proved to be an iterative process since leaks kept persisting. Eventually, after rigorous testing at depths of up to 20 feet and lots of epoxying, the leaks subsided. At times the members of AquaCat were frustrated but due to their hard work and persistency the threat of leaking diminished and the ROV was functioning underwater.

Lessons Learned

Many of the lessons learned were related to manufacturing. Aspects of manufacturing that the group learned about includemachining principles and equipment,lead time for parts and material cost. Regarding lead time for parts and materials, the engineering design group would occasionally be stuck without anything to work on because they were waiting for ordered materials to come in. This proved to be an issue,leadingto valuable time being wasted. Once the materials finally came in all at once, there often was an overwhelming amount of work to do.That being said, the engineering group members learned to plan ahead in the design process and to order materials well ahead of the time planned to use those materials for manufacturing.

Future Improvements

Though our team had great success with most of the design and testing process, certain alterations to the final design could prove beneficial to the project in terms of ease of fabrication and time management. Significant setbacks were caused while designing the end caps on the electronics tubes. Due to the tight tolerances inherited by using acrylic tubes, the caps did not fit initially, and further modifications had to be made. Care should be taken by future teams to ensure that the drawings are checked and consistent with the tubes being used.

Strain relief where the tether meets the chassis was also an area of concern. Though high strength, waterproof epoxy was used on all physical connections, constant strain eventually severed the seal, causing wire solder inside the tube to fail. By using a mechanical connection to secure the tether, such as an aluminum bracket, strain on these electrical connections could be better addressed.

Reflections

The UNH ROV project has proven to be a challenge, both from a design and fabrication standpoint. Though many obstacles have been and continue to be encountered, the overall experience has been positive and educational. There has also been an added benefit of the interdisciplinary nature of the project, as each member of the team has been forced to step outside of his comfort zone in order to achieve the end goal of a fully functional, practical ROV. Because of these traits, students looking for a worthwhile experience for a capstone project are strongly encouraged to continue the ROV project in the future.

References

[1]*SeaBotix BTD150 Specifications.* J. Rodocker, SeaBotix Inc., January 2007. <http://www.seabotix.com/products/pdf_files/BTD150_Data_Sheet.pdf>

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