INNOVOCEAN

Innovation in Marine Technology

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Vehicle:
RAGNAROK

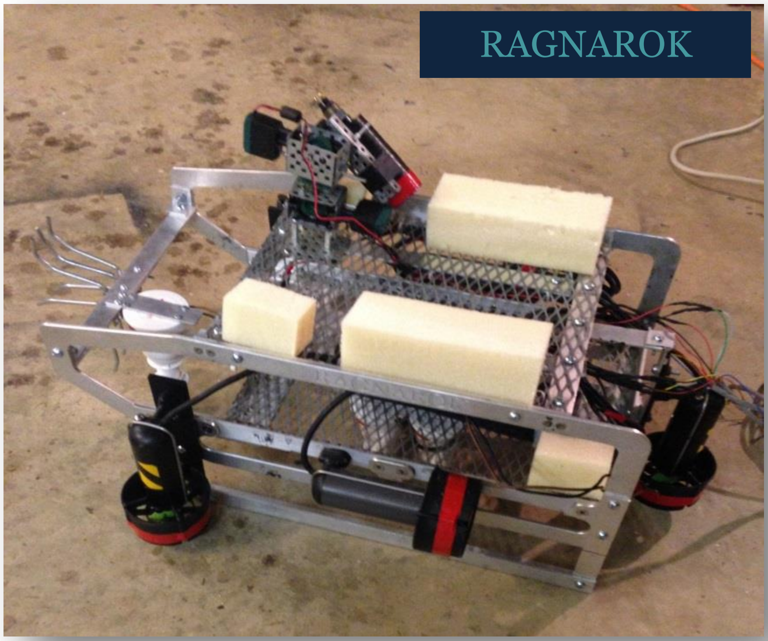
Carrollton High School,
Carrollton GA
2014

Abstract

In response to the Request for Proposals by the staff and conservationists of Thunder Bay National Marine Sanctuary, InnovOcean has designed and constructed a vehicle to help preserve their delicate maritime heritage resources. InnovOcean is an oceaneering company, created in 2007, that designs, constructs and operates Remotely Operated Vehicles (ROVs) to identify and preserve marine archaeological sites. Our newest vessel, Ragnarok, is equipped with the necessary elements to identify, document, and preserve the shipwrecks found in the Thunder Bay National Marine Sanctuary as well as to observe the surrounding environment.

Ragnarok's services include exploring and identifying unknown shipwrecks, preserving the site and surrounding area via trash and debris removal, and observing the environment by collecting microbial samples and measuring conductivity of groundwater emerging from sinkholes.

To perform these services, Ragnarok features components such as an advanced digital control system, powerful thrusters, panning cameras, and a passive ballast system. Our company has also developed five tools specifically for all services. These payloads include a measuring system, an agar collector, manipulators, and a multimeter. InnovOcean guarantees professional and safe exploration of maritime heritage resources.



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Company Profile

At InnovOcean, we are dedicated to not only producing efficient vehicles, but also to building strong customer relations. We ensure that each member of our company is qualified to provide the services required by our customers. At the onset of this year, each new member was partnered with an experienced employee in order to learn the basics. We then split the company into smaller groups specializing in particular areas. By enforcing this strategy, CEO Lucy Hutcheson, and COO Brendan Whitaker, were able to create the most productive and skilled company possible, along with preparing leaders and members with a high understanding of the engineering process for future projects. In previous years, InnovOcean has been much smaller, with no need for a company board or separate branches.

This year, management changes have been made to allow for better communication between groups and maximum member cooperation. There is an average of three weekly meetings of the full company, as well as several additional department group meetings. With a larger company, we have also broadened our span of knowledge and been able to prototype and explore new areas of technology.

When operating in groups, the manufacturing process can be fine-tuned, as certain employees are able to concentrate solely on the essentials of the vehicle like structure and propulsion, while others can focus in on specific payloads. During the construction process, a separate branch contains teams devoted to research, development, and marketing. Each group affects other aspects of the vehicle, allowing team members to interconnect between groups, gathering an understanding about all parts of the company.

When InnovOcean employees began brainstorming the line of vehicles to service the Thunder Bay National Marine Sanctuary, we created a set list of focal points that would permit the vehicles to operate at optimal efficiency. These points included:

- ☐Decreasing mass while increasing speed and maneuverability
- ☐Using simple, yet effective payloads to complete all services
- ☐Conserving materials and resources whenever possible
- ☐Practicing performance safety

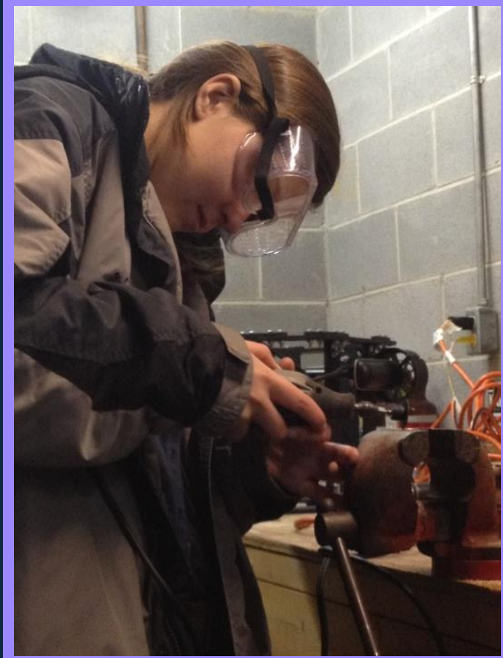
First year employees learning about buoyancy

Saturday pool practice with the ship

Safety

Safety is a top priority for InnovOcean. While constructing Ragnarok, all employees practiced safe habits such as wearing eye protection and closed toed shoes and tying back long hair. Additionally, InnovOcean operates in a safe environment. We clean our workshop after every meeting in order to ensure a consistently orderly workspace. By keeping our workshop organized, we decrease the number of potential safety hazards. Our workshop includes a tool wall for keeping equipment neat and contained, as well as various stations for different tasks. Our build station is set-up with power tools, safety gear, clamps, vices, etc., while the electrical station houses all wiring tools and provides an out-of-the-way area for soldering.

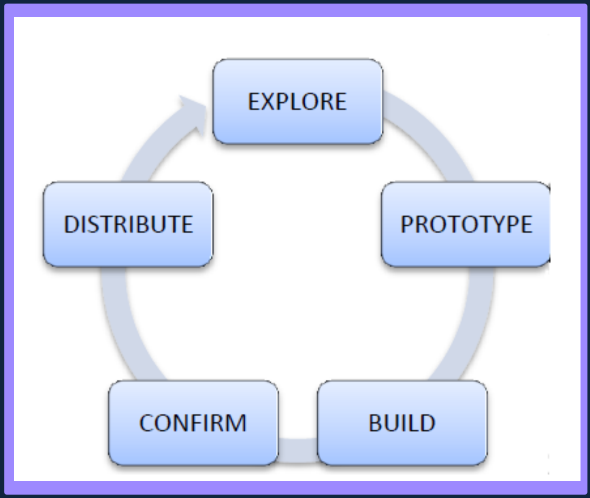
InnovOcean's dedication to safety is also evident in the numerous safety features on Ragnarok. Ragnarok incorporates an array of safety precautions, including a 25 amp fuse to protect the onboard electronic components. Additionally, all thruster and camera cords are pulled taut around the frame to minimize slack and prevent entanglement with any external or internal moving parts. All thrusters are equipped with safety partitions, and the tether is covered in an abrasion resistant wrap. Ragnarok's frame design also allows for all moving parts to be confined within the frame. Our control box also features safety stickers labeling all hazards warning employees to proceed with caution. The company follows a strict checklist before putting the ROV in the pool and during take down (See Appendix B). The protocols we take are enforced in order to protect all members from moving parts and "hot" wires.



Employee practicing personal safety

The Design Cycle

An important goal of InnovOcean is following a specific design process throughout vehicle construction and creation of marketing techniques. We have striven to ensure that every component of Ragnarok has been intricately designed and tested to perfection. To accomplish this, we created a design cycle that outlines all steps in the creation of our components. We first explore possible ideas and designs and prototype one or two of them. If the prototype is successful we build a full scale version and confirm its effectiveness. Once effectiveness is confirmed, we distribute the product to suppliers.



The Design Cycle

Design Rational

InnovOcean's newest vehicle, Ragnarok, performs exceptional services using six basic systems: Frame, Ballast, Thrusters, Cameras, Payloads, and Software.

Frame

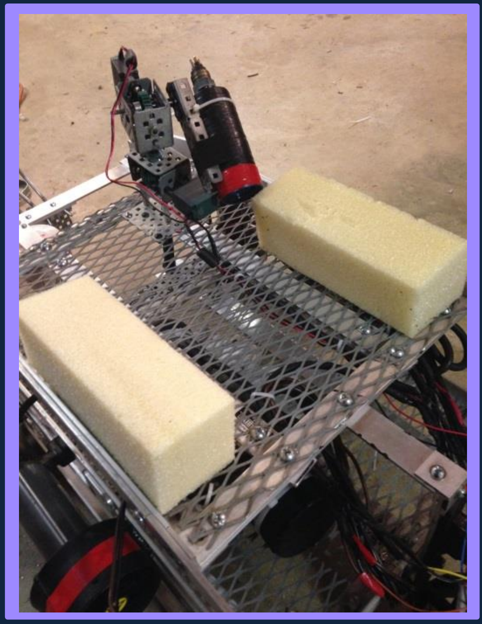
For the past six years, Innovocean has developed specialty frames for each of our vehicles based on what tasks they have had to accomplish. While this has allowed us to experiment with various materials and shape designs, we realize that creating a new frame each year is wasteful of both materials and money. For this reason, our team has decided on using a recycled frame from a previous model. Ragnarok's frame is composed of 20-24 grade aluminum creating a study yet lightweight overall structure. The frame shape and size was designed using the CADD program Inventor and then professionally cut at Advanced Precision Manufacturing, Incorporated. The original frame was 60.96 cm long, 30.48 cm wide and 20.32 cm high. To encompass all of our payloads on the inside of the frame we modified the structure by extending the bottom by 7.8cm. The extension skids are made of the same aluminum and are attached with bolts. Ragnarok's shape is a tapered rectangular prism; this shape allows the ROV to be more hydrodynamic. Because the edges of the ROV are rounded, water is able to move more smoothly across the top, making the ROV faster. Located at the center and top of the ROV are sheets of expanded metal to support the cameras and other tools. The expanded metal allows the ROV to move up and down with less resistance.

AutoCAD Inventor drawing of the frame

Attaching the extension skids

Ballast

Ragnarok's ballast system consists of two main passive polyurethane tanks mounted on top of the frame. During the design process, we realized we could streamline production by making two main symmetrical ballasts in addition to multiple ballast cubes. In past models, the vehicle featured asymmetrical cylindrical ballast tanks that required uneven placement to prevent the ROV from becoming lopsided. This year due to the low amount of water resistance created by the frame we were able to experiment with new forms of ballast. The pourable foam had a buoyancy rating of 27,215.5 grams per 0.0283168 cubic meters. This enabled us to supply the exact amount of buoyancy necessary after weighting Ragnarok. Once the two main 18.4 x 6.5 x 6 cm rectangular tanks were installed on the top level of the frame we used foam cubes that were all approximately 5 x 5 x 7 cm to reach neutral buoyancy. This new rendition would provide us with an accurate buoyancy level and the ease to make adjustments. To form a smooth surface that was large enough to cover the entire top of Ragnarok, we used a 30 cm x 48 cm baking pan and poured two-part two pound density urethane foam into the mold. The foam is closed cell, meaning that all air pockets inside the foam are separate. Should water fill one air pocket, it will not spread to any others, allowing the ROV to remain neutrally buoyant. To properly seal each tank, they were placed into a vacuum sealed bag under airtight lock and any excess plastic was trimmed off.



Large rectangular ballast tanks before sealing

Pouring the two part foam into baking pan

Propulsion

A major focus in this year's vehicle design was maneuverability, and this was given much consideration when deciding thruster orientation. Ragnarok features a total of five thrusters, two for lateral motion and three for vertical motion. All five are Seabotix thrusters which provide much more power than modified bilge pumps, which we have often used in the past. The two lateral thrusters are mounted in the middle of the outer edge of the frame. Each thruster draws 4 amps of power and provides approximately 28.4 N of thrust. Two of the three vertical thrusters are mounted onto the front outer edges of the frame while the third has been mounted on the back center creating a triangle. To minimize drag, the vertical thrusters are mounted flush with the expanded metal base panel of the ROV. All Seabotix thrusters are positively buoyant and feature safety partitions around the propellers to protect both InnovOcean employees and marine life.

Cameras

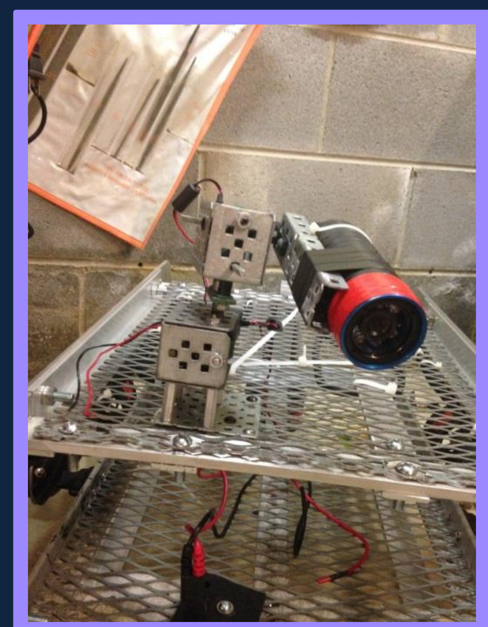
Ragnarok houses four marine cameras from Lights Camera Action. Our design team quickly realized that in observing shipwreck sites, having extra camera views would be valuable. However, having a separate camera for each viewing space would be highly impractical both spatially and financially. We approached the idea of a rotating camera warily because of failed development in the past, but we decided that it would be imperative for the success of our vehicle and therefore put priority on its development. We began brainstorming and drew detailed sketches of each idea. We designed several unique systems--one consisting of a camera on a track around the circumference of the frame, another with multiple cameras each with their own individual movement. After considering these designs, we chose to pursue prototyping a system entailing of one panning camera and one rotating camera. Each system consists of a short single axle connected via gearbox to a servo motor. The other two Blu-Vue cameras are positioned to give us an alternate view to our payloads. Our cameras also feature 6 white Light Emitting Diode (LED) lights for vision on the ocean floor.

Control System

Our current model of Ragnarok houses InnovOcean's most advanced control system to date. In the past, we have employed various hardware-based systems that involved no software in their design. Such systems were comprised primarily of toggle switches that only allowed for on/off control of our thrusters. As our ROV technology developed, we recognized the need to develop our controls as well. This year, we have once again used an Arduino Uno microcontroller as the "brain" of our system. Each thruster has been connected to a Sabertooth dual 5A motor driver that receives power from our 12 volt battery. The power is then redistributed it to the thrusters based on pulse width modulation (PWM) signals from the analog pins on the Arduino. The fluctuating PWM values allow for our thrusters to run with varying speeds. This is an essential ability for the ROV to have because it provides more intuitive control over the vehicle and allows for fine adjustments in the water.

Traditionally, we have wired our vertical thrusters to the same motor controller.

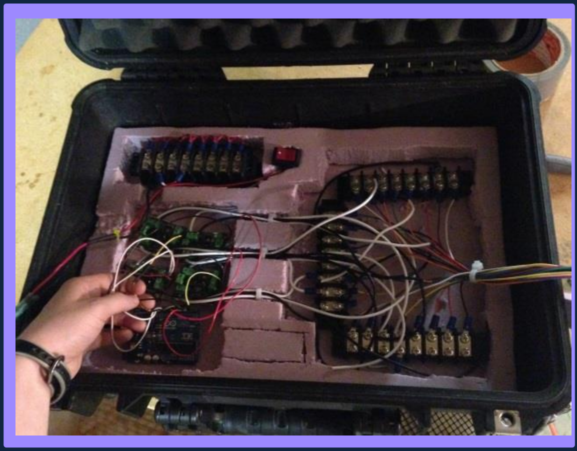
Vertical Thruster with safety precautions



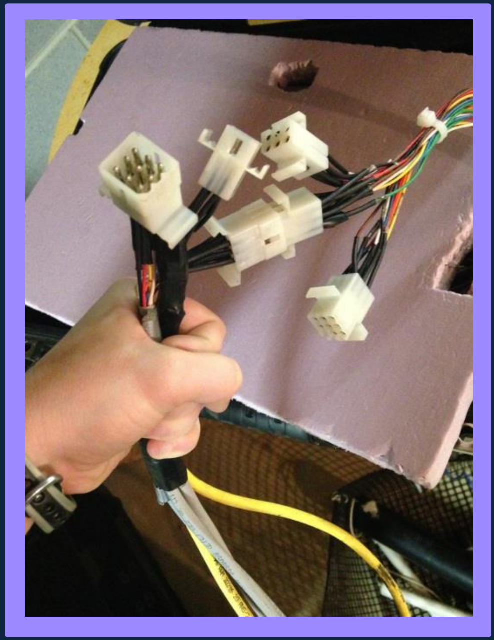
Top camera with rotating and panning features

Although with the improved system, we were able to run two leads off one motor. This enabled us to, not only, link the three vertical motors together but to have a total of eight power sources. Each lateral thruster requires its own lead due to the pilot operating them at different times for turning. The remaining leads were then occupied by the rotating cameras, the agar sample collector, and the vacuum manipulator. With four more leads than last years control system, we were able to upgrade all switches to run through the Arduino Uno microcontroller, making the X-box 360 controller our only piloting device.

In order to keep all circutry untangled and protected, a foam sheet was carved into for housing the teminals, motor controlleds, and arduino. An additional sheet was placed over top as a cover for when the control box is open permitting easy maintanence as well as protection. The entire arrangement was sealed in a water tight Pelican case that features a point-of-no-tension connecting the tether through two 9 pin and one 6 pin connectors . Ragnarok's tether includes an air hose, 24 leads, and four camera cables all covered in an abrasion resistant tether wrap.

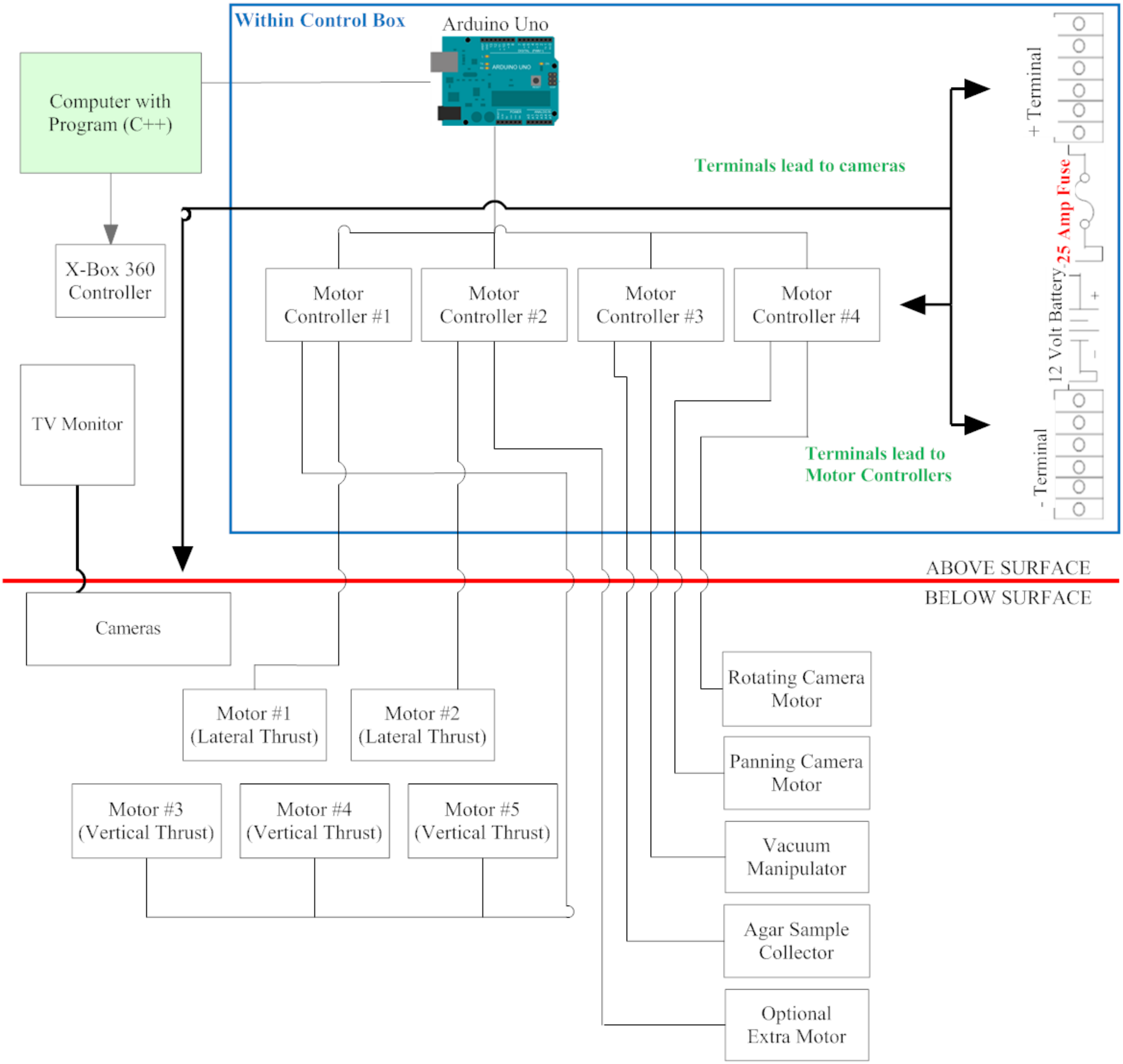


Control Housing



Tether connection to controls

System Interconnection Diagram



Payloads

Tape Measure System

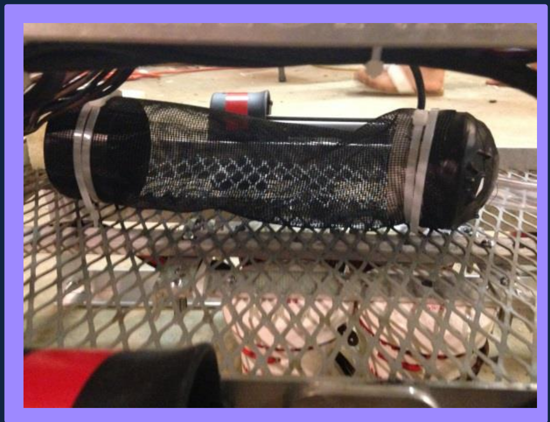
Prior to the Gray's Reef Regional Competition our company fabricated a device that operated similar to a tape measure. The only problem with this prototype was that the retraction process was slow and would occasionally get stuck. We soon realized that coming to the surface to rewind our tape measure between each dimension measurement was the only way to complete the task. This waste of time put us at a major disadvantage and there was still no guarantee that our final measurement would be accurate. This led us to the idea of using a programming approach instead of mechanical performance. After deciding to implement a simple scale, we created a 40cm "XYZ" axis out of Polyvinyl Chloride (PVC) piping. On our initial decent the ROV will place the PVC scale flush with the corner of the ship. By splicing our camera feed we are able to view the mission on the monitor and simultaneously on a laptop. It then becomes a quick task of taking three screenshots of the ship and scale from the laptop. Once the screenshots have been gathered the copilot will transfer them into AutoCAD where the ship's dimensions will be based off the scale. During practices we have found that this method is extremely time efficient and gives off accurate measurements each time.

"XYZ" Scale

Agar Sample Collector

In order to detect groundwater rich in sulfur, we have developed a tool to easily collect microbial samples. After exploring many mechanical scoop-like alternatives, we decided to pursue a vacuum system because it allows for quick, efficient collection. Our design starts with a modified bilge pump which extends into the agar sample during the mission run. Once the bilge pump is turned on, agar is drawn inside and forced out the other end in a finer form where it is kept until the vehicle resurfaces. We manufactured a holding container made of fine mesh to ensure the agar does not leak. The bilge pump was placed on the front of the frame where the pilot has the best possible access to the agar sample. The mesh container is mounted within the frame using zip ties to guarantee effortless removal of the sample for further examination on deck.

Modified bilge pump to collect agar



Agar collection container

Vacuum Manipulator

Arguably the most important ability of any ROV used in marine exploration is manipulating its environment--removing debris from workspaces, collecting samples and navigating closed spaces. To complete such tasks, InnovOcean's prototype and design team came together to fabricate a manipulator from scratch, which was much more cost efficient than purchasing one as we have done in the past. After much consideration, our team designed a vacuum-like system composed of four bilge pumps arranged in a square which are mounted on the bottom side of Ragnarok. The bilge pumps are connected with tubing and joined into a funnel point at the bottom. When maneuvering Ragnarok over the bottles or ceramic plate, the bilge pumps create a strong suction allowing us to gain control of each object.

Bilge pump system used for vacuum manipulator

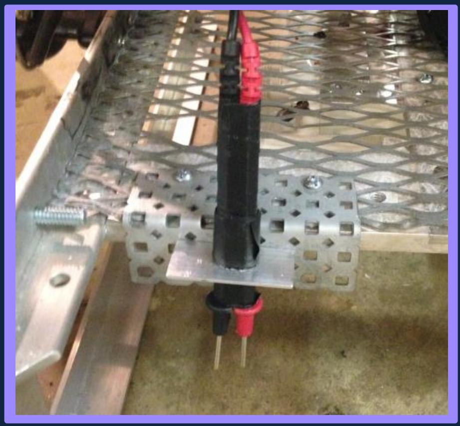
Hook Manipulator

Instead of completing relying on our manipulator to complete tasks, we decided to include an alternative method to maneuvering objects. In past shipwreck explorations, we have often been challenged with opening doors and hatches and have found that, surprisingly, hooks are more valuable than our manipulator in this respect. Hooks do not require any mechanical manipulation, which makes them simple to use and install. In response to our past successes, hooks were included on Ragnarok to ensure swift opening and closing cargo containers as well as easy lifting of the anchor line to the surface.

Hook Manipulator

Multimeter

To measure the conductivity of groundwater, we have implemented a modified multimeter into our system. We have extended the leads from the meter from the surface through the tether to prongs mounted on the ROV. Using the multimeter, we can measure the resistance in ohms (Ω). If the resistance decreases, then we know we have identified a more conductive area.



Multimeter

Challenges

Throughout the duration of time spent developing Ragnarok, InnovOcean experienced various obstacles that we had to overcome. Company members experienced challenges ranging from company management to technical and construction issues. While many of these problems were arduous to resolve, we as engineers, were able to brainstorm and work together to surpass these encounters and decide on other methods of getting the job done.

One of the company's major struggles this year was the push for time, as we have never been very good at prioritzing. Towards the start of the season we began exploring ways to technologically advance by adding new features to the vehicle such as an onboard control system and an active ballast system. The team was actually ahead of schedule up through December until we learned that the Gray's Reef Regional competition had been pushed forward to March. This deadline change launched InnovOcean's production into high gear so that all deadlines could be met and all standards exceeded. Another thing that has caused InnovOcean's need to accelerate production rates was the company expansion.

This year the number of employees has almost tripled. While we expect to benefit from this growth, it has required an inordinate amount of time training new employees contrarily taking away senior efforts that could be spent elsewhere. Not only, was learning how to prioritize a challenge, but learning to manage a much larger company was also a demanding task. To ensure that each member was informed of protocols, schedules, and the details of Ragnarok, spreadsheets were created organizing jobs and meeting dates. Each member was given the opportunity to get in groups and work in different fields of the company.

Additionally, our construction branch of InnovOcean has had a number of ordeals to endure. The measuring system was one payload that required some consideration. We initially began with a similar mockup to the measuring device used in 2010. To improve the self-retraction aspect of the device we knew we would have to use something stronger than rubber bands to suspend the tape from either side of the frame. We explored many options and surgical tubing was confirmed as the strongest. However, when fully extended the surgical tubing

Corroded Seabotix Claw

Employees prototyping new manipulator system would not unravel due to internal suction. It was apparent that having a hollow tube would not suffice. Looking to switch materials, testing the effects underwater, and gluing the tubing shut were options that were evaluated. We also weighed the pros and cons to cutting the tubing lengthwise down the middle. This would lower the strength of the tubing but would create a system that would work flawlessly. For the final product we decided to cut the tubing lengthwise and pre-wind the system so it has enough strength to retract all the way.

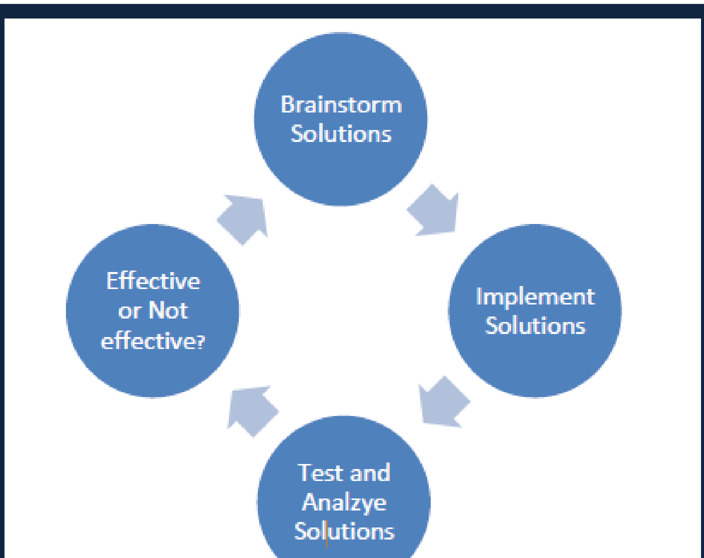
However, the problem that affected us most was when our high powered manipulator failed. InnovOcean was extremely dependant on the manipulator to provide customer satisfaction while completing Ragnarok's services. Unfortunately, after years of use, the overused motor corroded. As soon as we realized that repairs were not an option, we began prototyping and designing various claw-like manipulators that would grab and transport objects on the seafloor.

The idea of using VEX materials was pitched and a model was created that was thought to complete such jobs just as well while weighing less than the purchased manipulator. However, after testing, we realized that the VEX parts and motors were simply not strong enough to carry the loads we needed to carry. Soon, we discovered that our school's 3D printer could be used for our purposes. Our prototype and design team designed a manipulator very similar to our previous one using computer software such as AutoCAD and Inventor. During this process, we ordered waterproof linear actuators that would open and close such a manipulator. Soon, a manipulator was created. Although it seemed to work well, we realized that it was a safety hazard. The plastic printed model simply could not withstand the force of the linear actuators. This led us to step away from the typical claw-like manipulator and has pushed us to think outside of the box.

Following much distress, it became clear that instead of focusing on designing the typical claw-like manipulator, we needed to design payloads that would successfully complete the *specific* mission tasks. We needed payloads that would unlock and open hatches, remove sensor strings, and pick objects off the seafloor. So, InnovOcean's members as a whole came together to brainstorm ideas to complete such tasks. Several ideas were suggested including using hydraulics and a scoop, but eventually we decided to use a structure of hooks and a vacuum manipulator.

The structure of hooks was designed in a way so that it could be used for various tasks: removing the sensor string, removing the anchor line rope, and manipulating the cargo container. The vacuum system was devised so it would efficiently pick up the bottles and ceramic plate off the seafloor. It was constructed out of four bilge pumps arranged in a square. The suction created by the bilge pumps was strong enough to securely acquire the items. After such success, InnovOcean was proud to have overcome such challenges and learn from this experience.

Troubleshoot Process



Future Improvements

InnovOcean is constantly looking for ways to advance; there is always room for improvement whether it be in the design, function, and controls of the vehicle or even in the structure of the research branch of our company. In past iterations of our vehicle, we focused primarily on having a working control system and sacrificed maneuverability for the sake of simplicity. We have found that while a simple system can get the job done it can also limits maneuverability and other key features. With the development of our knowledge we decided it was best to further advance the electrical aspects of our design. We were recently able to upgrade from toggle switches to an Xbox 360 controller by incorporating an Arduino microcontroller as the central component. The next step would be progressing to an onboard control system. In the past, the maneuverability of our vehicle has been compromised due to a thick, cumbersome tether. The benefits of having all our electronics housed within the ROV would be reducing the size of our tether, and the addition of a positively buoyant control box. Although our thruster orientation allowed for maximum lateral rotation, we needed a successful way of moving vertically in the water column. Although we knew we could obtain this force with vertically mounted thrusters and bilge pumps, we thought that a smaller active ballast positioned in the center of the vehicle would assist in upward motion. Unfortunately, due to time constraints, we were unable to fully evolve the system with the idea of having a partially active ballast system. These are improvements we soon hope to make.

Reflections

At the onset of the year, it was very clear that as a team, while we were all united through one common goal, we were also divided into three separate groups: seniors, returning members, and new members. In a way, this was actually very beneficial for us because it provided three different perspectives that we would not have had otherwise. With that said, we also thought that in reflecting on this year's experience, it was important to take into account these three insights, so we asked each group to collectively craft a statement to represent their experience with InnovOcean this year.

Senior

"As seniors, we came to the realization that this year was less about our own experience and more about teaching the next generation of ROVers. It was definitely hard to relinquish that power and let the younger members take over, especially because of how much the program that has meant to each of us. But it's also for that reason that we had to let go. In order for the team to flourish and thrive, they have to be able to do all of the work without us next year. Being part of this team has also helped solidify some of our academic pursuits. Many of us now know that we would like to enter an enginnering career after having been introduced through ROV."

Returning Member

"As returning members, this year we were challenged to step up as leaders on the team. It's nerve wracking as well as exciting to know that we'll be carrying the team next year, and while we are definitely going to miss the seniors, we feel prepared to step up to the plate. Watching this year's senior group make their post-high school plans, we've realized how valuable ROV has been in helping us solidify our interests in STEM, so we have at least an idea of where we want to apply for school and what we would like to do after."

New Member

"This year has been a year of new experiences, learning, and new friendships. We have learned much from these past months and are excited to keep expanding on that knowledge to benefit the team. So many of us didn't really know what 'engineering' was, and ROV has been a great introduction. Now not only have we recognized the value of math and science applications in robotics, but we have gained insight on the importance of STEM skills across disciplines."

Acknowledgements

InnovOcean would like to recognize several sponsors and individuals for their support and help throughout this year. InnovOcean members would like to thank Greenway for their generous donation in August to fund vital materials for the upcoming season. The team would like to acknowledge Carrollton High School for allowing us to use the STEM equipment to help construct our frame and add special features, like rotation to our cameras. We would like to thank Mr. Matt Greene, who willingly devoted some of his time to aid us in designing the logo by introducing us to new software. We appreciate the support of Sunset Hills Country Club and

Carrollton Lakeshore Recreation Center for permitting us to utilize their pool for practice. Additionally, we would like to give a special thanks to our parents and families for their advice, inspiration, and encouragement as we take on new challenging endeavors. Two individuals, in particular, have gone out of their way to make this year possible; Papa Sam and Mrs. Ann have offered the tea m a meeting space where we can collaborate and use their workshop for construction. Without the support of our mentors, Kristi Bradford-Hunt and William Melton, none of our accomplishments would have been possible. They have ensured that we stay organized, have guided us along the way, and have never stopped believing in us. We appreciate all that these individuals and organizations have done! Finally, InnovOcean would like to acknowledge Gray's Reef National Marine Sanctuary, The Thunder Bay National Marine Sanctuary, and MATE for giving us the opportunity to participate in this amazing experience.

Servicing Warranty

To ensure customer satisfaction and reflect InnovOcean's confidence in our product, Ragnarok, a one year servicing warranty is included with each vehicle. If at any time a system fails due to a technical malfunction, an InnovOcean engineer will fix and/or replace that part or system at no expense to the customer.

APPENDIX A: Budget

Amount	Vendor	Description	Balance
		Deposits	
$712.93	ROV Account	2012-2013 ROV Balance	$712.93
$2,150.00	ROV Team Members	Team Dues	$2,862.93
$1,327.00	Georgia Greenhouses	Poinsettia Fundraiser	$4,789.93
$750.00	Greenway Medical Technologies	Greenway Project	$5,539.93
		Expenses	
$715.00	Sea Botix	Thruster	$4,824.93
$241.34	Provantage	Power Supply 120VAC - 60AMP	$4,583.59
$175.11	Security Solutions	18 Gauge, 8 Lead Wire (Tether)	$4,408.48
$255.59	Tap Plastics	Frame Plastic - HDPE Plastic 3/8"	$4,152.89
$58.04	Home Depot	Supplies for props	$4,094.85
$3.56	Home Depot	3/4"X1/2"X1/2" PVC Tee	$4,091.29
$5.28	Home Depot	1/2"X2' FlowGuard Gold Pipe	$4,086.01
$21.00	Intl. Restaurant & Bakery Eqpt.	Full Size Baking Pan 4" Deep	$4,065.01
$85.90	U.S. Composites Inc.	2 LB - 2 Part Urethane Pour Foam	$3,979.11
$3.88	Home Depot	4" PVC End Caps	$3,975.23
$2.60	Home Depot	U-Bolt #320	$3,972.63
$2.36	Home Depot	3/4" Sheet Metal Screws	$3,970.27
$2.12	Hobby Lobby	Plastic Bottles (Agar Sampler)	$3,968.15
$4.97	Home Depot	Hyde Painters Pyramid 10 Pack	$3,963.18
$3.77	Home Depot	Loctite 1 Minute Static Mix Epoxy	$3,959.41
$16.84	Walmart	Supplies	$3,942.57
$7.80	Home Depot	Supplies for Agar Sampler	$3,934.77
$19.23	Home Depot	4" Bulk Heat Shrink Tubing	$3,915.54
$47.04	Walmart	Pump Kit	$3,868.50
$34.99	Home Depot	Supplies	$3,833.51
$24.10	Home Depot	Supplies for Agar Sampler	$3,809.41
$18.79	Home Depot	Sheet Metal	$3,790.62
$128.67	Walmart	Supplies for Vacuum Manipulator	$3,661.95
$42.94	Amazon (Molecular-R)	Molecular-R Agar (1 pound)	$3,619.01
$369.60	Wholesale Market	Linear Actuator (x2)	$3,249.41
$5.79	Home Depot	Tubing for Vacuum Manipulator	$3,243.62
$32.64	Home Depot	Foam for Tether	$3,210.98
$249.96	Sabertooth	Motor Controllers (x4)	$2,961.02
$14.38	Home Depot	Zip Ties and Electrical Tape	$2,946.64
$35.27	Walmart	Bilge Pump for Agar Sampler	$2,911.37
$77.26	Hobby Lobby	Supplies for Poster	$2,834.11
		Reused Items	
$2,249.84	Seabotix	Thrusters	
$3,751.32	Lights, Camera, Action	Blu-Vue Cameras	
$95.84	Home Depot	Aluminum Frame	
$119.87	Amazon	Tether Wrap	
$67.96	Pelican Company	Pelican Control Box	

Total Cost to Build Ragnarok:	**$1,564.21**

PRE-MISSION LIST

Physical

- All items attached to ROV are secure and will not fall off (Check connections)
- Hazardous items are identified and protection provided.
- Propellers are enclosed inside the frame of the ROV or shrouded such that they will not make contact with items outside of the ROV (Check Safety Partitions)
- No sharp edges or elements of ROV design that could cause injury to personnel or damage to pool surface

Electrical

- Standard male Banana plugs to connect to MATE power source.
- 25 amp Single Inline fuse or circuit breaker within 30cm of attachment point (Check Fuse)
- No exposed copper or bare wire (Check connections, use electrical tape or liquid tape if required)
- No exposed motors
- All wiring securely fastened and properly sealed (check connections, especially at control box and at conduit)
- Tether is properly secured at surface control point and at ROV
- Any splices in tether are properly sealed
- Surface controls: All wiring and devices properly secured
- Surface controls: All control elements are mounted with wiring inside an enclosure.

DECK COMMAND LIST

"Going Hot"- This is the pilot's signal to all deck members that the ROV is about to be powered on.

"All Hands Clear" - Everyone should remove hands and other extremities from the ROV and its moving components.

"We're Cold" – This is the pilot's signal to all deck members that the ROV has been disconnected from the battery and is okay to handle.

"**Tether**" – This tells the tether manager to feed more tether into the pool.

APPENDIX C: Software Block Diagram