BLUE RAY ROV

9TH Annual MATE International ROV Competition

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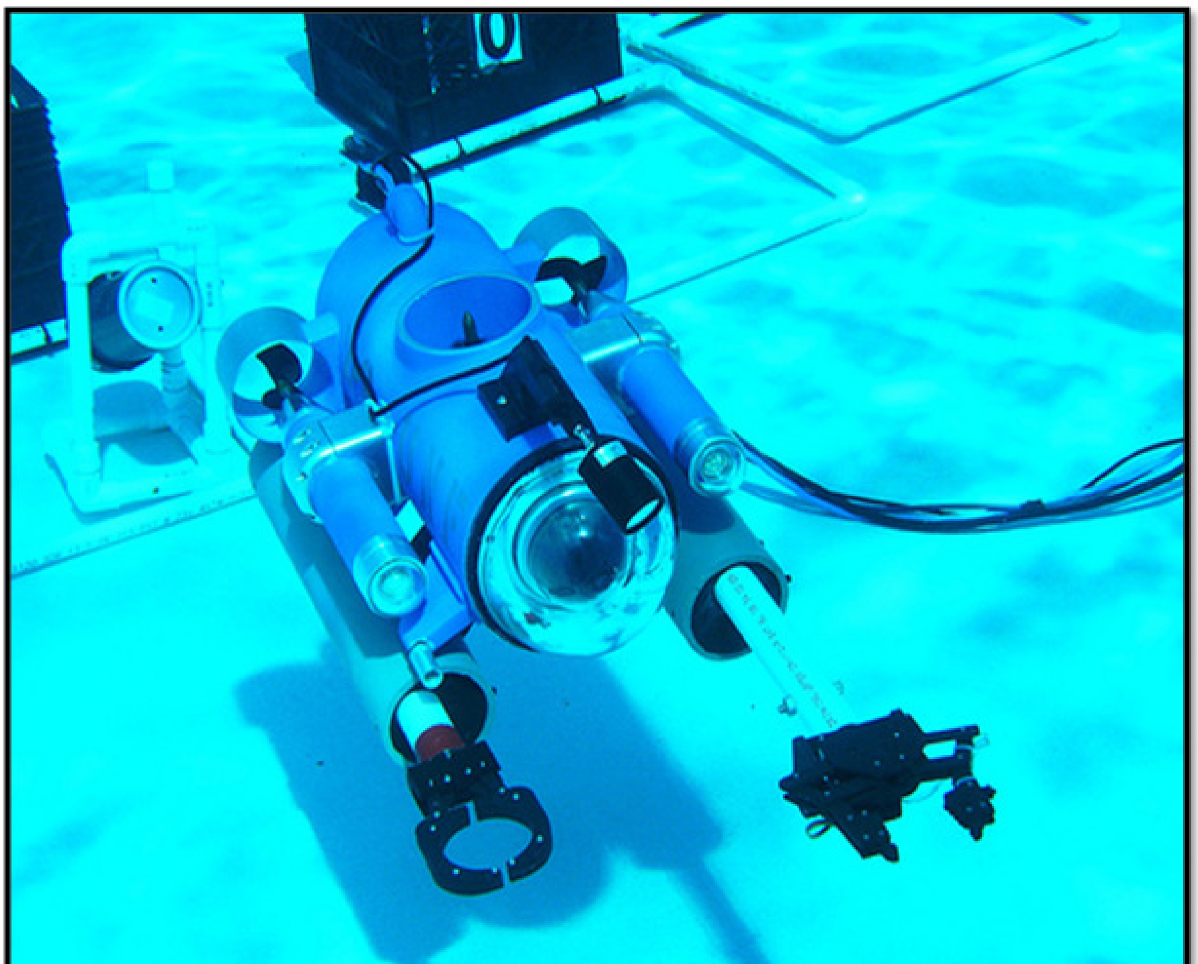

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Abstract

This school year, the UNF ROV team designed our first ever ROV for the 2010 MATE Remotely Operated Vehicle (ROV) competition. Our Vehicle, named "Blue Ray", is an underwater submarine designed for various tasks in the field of marine engineering. The purpose of this ROV was not only to compete in the 2010 MATE competition, but to also aid in marine research in the St. John's River. Our ROV is made of PVC and aluminum and has a mass of 13.6 kg and an overall dimension of 29 cm high x 38 cm wide and 81 cm long. The overall design focus of the ROV consists of robustness, and functionality for multiple applications. The ROV hull is designed to be extremely rugged as well as streamlined for improved maneuverability. The ROV has two multi-functional servo-controlled grippers. Its main gripper is a 2-axis manipulator capable of 2-degrees of motion for added functionality. The ROV has 3 thrusters, two on each side to act as a differential driving system, and one vertical center thruster for elevation control. Two cameras are mounted on the ROV, one multi-axis camera for multiple viewing angles; the other is a stationary camera housed on top of the main gripper to aid in precision gripper control. Hydrophone and temperature sensors are also mounted on the hull of the ROV. These features allow the pilot to successfully execute a wide variety of tasks, from the MATE ROV tasks to sensor collection in the St. Johns River.

Design Rational – Tasks

The UNF ROV team decided to focus design on performance and functionality. Thus the priority design tasks were for stability, neutral buoyancy and three-dimensional mobility, with an excellent camera system. These design criteria were initially implemented before the MATE tasks were announced. While designing the ROV to perform all of the MATE competition tasks, careful monitoring of the design was also implemented to keep the ROV versatile and adaptable to other applications, such as research in biology and water quality for the St. Johns River estuary in Jacksonville Florida. The MATE ROV tasks and how we planned to accomplish them are discussed below.

Task – 1: Resurrect HUGO

The first task in this year's MATE ROV competition involved heavy underwater manipulation and dexterity in order to resurrect the Hawaii Underwater Geological Observation (HUGO). As a result, the team put heavy emphasis on the robotic manipulators that are equipped on the ROV. The ROV's two electric grippers are housed in the pontoons of the ROV located on opposite sides of the hull. The first gripper is a 2-degree of freedom, servo-controlled, parallel gripper that is used for the majority of the manipulation required for the competition. This gripper is shown in Figure 1.

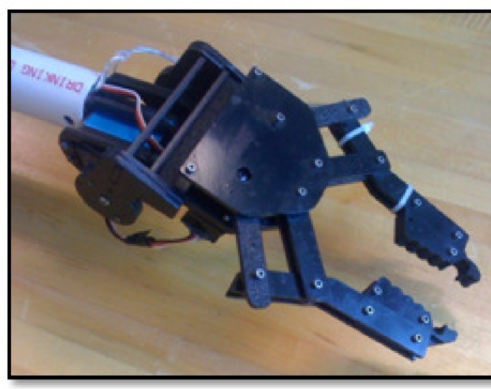

Figure 1. Primary 2-axis gripper

This gripper is housed in the pontoon located on the port side of the ROV (refer to figure on the cover page). The gripper fingers are designed with a notch cutaway to help aid in removing the pin that attaches the HRH to the elevator. The second servo actuates the wrist of the gripper to give the operator the ability to control the pitch of the gripper. This feature was designed to accommodate the 45-degree angle on HUGO's junction box where the HRH's communications connector plugs into. The ROV is also equipped with a camera that is housed on top of the primary gripper. This gives the operator the ability to clearly see the objects that are being manipulated. The ROV's hydrophone is housed in between the pontoons of the sub in a fabricated aluminum mount. The housing's conical design gives it directionality by allowing only sound waves in the forward direction to reach the hydrophone. Placing the hydrophone in between the two pontoons of the ROV also aids in reducing noise coming from the sides of the sub, thus increasing its directionality.

Task – 2: Crustacean Sample Collection

The second task of collecting crustacean samples was enabled through the design of agile ROV maneuverability. The ROV was designed with a priority on neutral buoyancy, and this aspect allowed the ROV to not only easily enter the cave and traverse to the back, but also to hover in place while the crustaceans are being collected. The primary gripper was designed with complete positional control. Instead of having a gripper that only has an open and close orientation, the gripper on the UNF ROV has intermediate positions. This allows for accommodation of various sizes of crustaceans without crushing them. This feature also increases the dexterity of the gripper because it allows the operator to close the gripper slightly and position it as it approaches to grab the crustacean. The second gripper, shown in Figure 2, is located on the starboard side of the ROV and is used for carrying a container that houses the crustaceans.

Figure 2. Secondary gripper

This allows the operator to place three crustaceans in the container, shown in Figure 3, and advance them to the surface in one shot to reduce mission time.

Figure 3. Crustacean Container

This gripper also serves as a backup to the sub's primary gripper should it ever fail.

Task – 3: Sample Vent Site

The ROV is equipped with a temperature sensor that is used to measure the temperature of the vent site in the third task. The temperature sensor is housed on the outside tip of the primary gripper on the port side of the ROV, enabling the ROV to maintain a safe distance from the hydrothermal vent circulation.

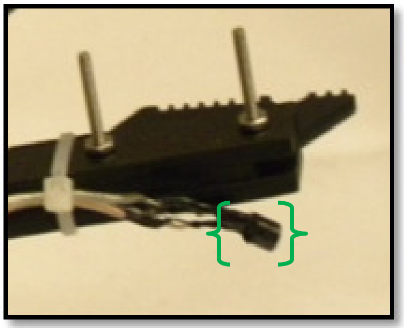

Figure 4. LM335A Temperature Sensor

Figure 5. Bacterial Collection Tool

Placing the sensor in this location also allows for the operator to easily position the sensor in each of the three vent sites in the competition and obtain accurate readings. The temperature sensor is controlled through the main controller board on the surface. The temperature sensor can be turned on and off with a transistor via pushbutton on the surface. This function allows the operator to only accumulate temperature readings as required. The temperature readings are exported to a Labview program script in real-time [1]. The Labview program is coded to actively display the temperatures and plot them. The data can then be exported to Microsoft Excel where graphs of temperature vs. chimney height are made. The primary gripper was used to collect the vent spire sample and carry it up to the surface.

Task – 4: Bacterial Collection

The fourth task involved collecting a bacterial sample that is simulated with agar. For this task, the team designed a tool, shown in Figure 5, that specializes in slicing through the surface and cutting out a core sample of the agar. This tool consists of a cylindrical blade that can not only cut out and collect the sample, but is also designed to be employed *in situ* by our secondary (starboard side) gripper.

The tool sits flush with the gripper and allows the operator to firmly insert the tool into the sample and collect a full depth core of agar.

Design Rational- ROV Components

ROV Hull

The horizontal thruster mounts utilize a clamp type design that provides a means of easily removing the thruster to facilitate maintenance or simply swap units as required. They are machined from 6061 2x2' aluminum stock and use stainless socket head screws to fasten and adjust the clamps as necessary.

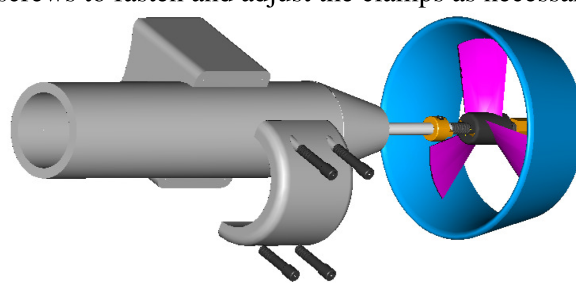

Figure 6. Thruster Mounts

The design of the hull was meant to provide stability, space for onboard equipment, and to provide some appeal to the overall look of the ROV. The bulk of volume displacement occurs in the volumetric area of the main hull which places the center of buoyancy near the center line of the hull. The pontoons, which are mounted significantly lower than the hull, provide a place for ballast to be stowed. As a result of the mass that is associated with the ballast, the center gravity is kept at a good distance below the center of buoyancy. This combination creates a stable platform that keeps the ROV in a perfect horizontal position with superb self righting capabilities.

The Hull, shown in Figure 7, was crafted using 15.2cm schedule 40 PVC through which a hole was cut to provide housing for the vertically mounted center thruster. The center thruster is surrounded by a 10.2cm diameter tube again using schedule 40 PVC that was secured to the main hull using several layers of marine epoxy reinforced with a fiberglass mesh to enhance the structural integrity of the joint. The final layer of epoxy was smoothed down to create the illusion of a single piece hull.

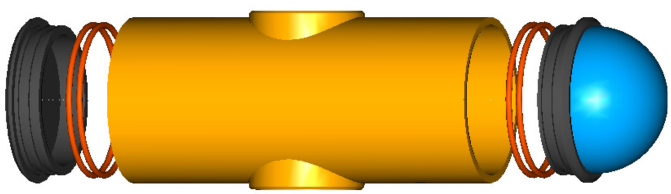

Figure 7. Hull – Exploded View

Both end caps were machined from solid 17.8cm diameter delrin stock. Delrin is an extremely versatile acetal plastic with excellent durability and machinability making it a practical material for our purposes. The caps were designed to be plug type devices that utilized double o-rings made of silicone rubber which is known for its resistance to weathering. The o-rings were sized appropriately to provide both stretch and compression of the silicone to ensure the greatest seal without exceeding material properties. The front cap houses a 14cm acrylic dome that is set in place using marine epoxy.

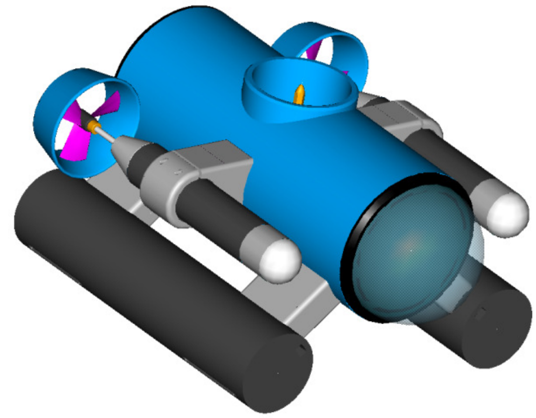

Figure 8. Hull – Isometric View

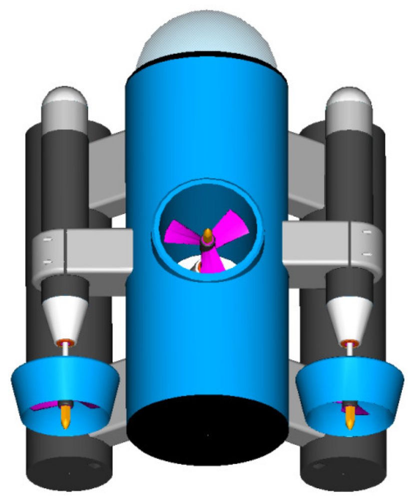

Figure 9. Hull – Top View

The pontoons are comprised of 7.6cm schedule 40 PVC and are secured to the main hull using aluminum blocks to provide the desired spacing.

Thrusters

The propulsion system is comprised of three S1 thrusters, two arranged in the horizontal plane and one in the vertical that allows for depth control. At the heart of each S1 thruster lies a 12V, 10,000 rpm, brushed type Johnson motor that is commonly used in kiddy car applications. The stock motor produced significant torque levels at high rpm that were, unfortunately, not consistent with the operating range suited for our application. Furthermore, the amount of current that each motor was capable of drawing at max power exceeded 15 amps; a current draw well beyond our power budget. To enhance the overall performance of the motor, a gear train was fitted to reduce the rotational speed, improve torque, and significantly reduce power consumption. The gear train consists of a planetary gear head with 4:1 reduction ratio that could be fitted directly to the output end of the motor. The addition of the gear train culminated in a thruster that consumed 3 amps of current at maximum power. Using a tachometer, the maximum rotational speed of the thruster was clocked at 1500 rpm while submerged and under the load of the propeller. The resulting rotational output from our geared motors fell within our intended propeller operating range of 800-1600rpm.

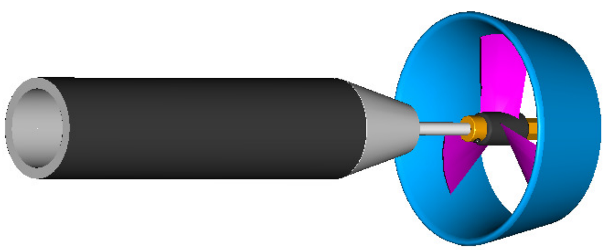

Figure 10 Thruster Diagram

The motor torque is transmitted to the propeller via a 0.6cm stainless steel shaft which is fastened to the output shaft of the motor using a homemade brass coupling. The propeller uses a dog drive system that is commonly utilized by RC boat enthusiasts. The system consists of a collar that is secured to the shaft using a set screw. The collar has two male prongs that engage two receivers that are machined into the propeller. A nut is then used to keep the propeller securely engaged to the drive collar. This set up is depicted in Figure 11.

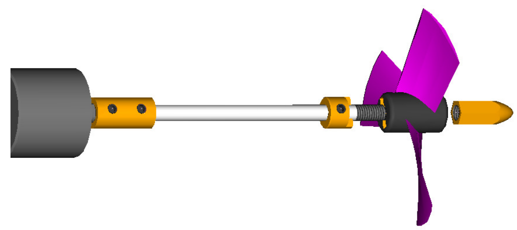

Figure 11. Shaft and Couplings

The S1 thruster housing consists of 3.8cm schedule 40 PVC which is fitted with an aluminum tail cone on the back end and an aluminum light fixture at the front end. The aluminum tail cone, shown in Figure 12, utilizes heat conduction properties to help conduct heat away from the motors when they are being operated at heavy duty cycles. The tail cone uses a close tolerance system that requires that they be press fit into the PVC housing using silicone to help seal and secure them in place. The potential for water leakage into the tail cone was successfully thwarted by using a nitrile spring compression lip seal. The seal was press fit into a precision-bored hole and backed with a hydrophobic grease pack. The grease pack helps to reduce friction and wear by lubricating the seal while simultaneously amplifying the effectiveness of the lip seal with increasing depth and pressure.

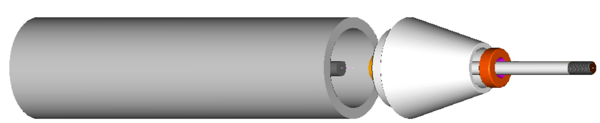

Figure 12. Tail cone and Lip Seal

Several propeller configurations were tested before settling on the final design. To protect the propeller from damage and entanglement of the ROV tether, a shroud, shown in Figure13, was implemented into the design of the thruster. However, comprehensive thruster testing demonstrated substantial decreases in both speed and thrust after the implementation of the shrouds. It was quickly realized that the current RC boating propellers were neither designed nor suited for a shrouded application. In an attempt to find a solution to this problem, exhaustive research was conducted on how to construct suitable replacement propellers. However, plagued with limited manufacturing resources, we were forced to resort to retrofitting an existing propeller, obtained from VideoRay's GTO series thrusters [6], onto our thruster assembly. The propeller is designed and well suited for a nozzle application, which is what we intended on implementing. The propeller is a 100 mm, three bladed design that significantly increased the propulsion capabilities of the S1 thruster.

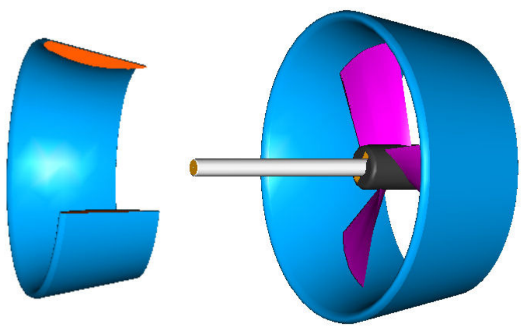

Figure 13. Kort Nozzle with Cross Section view

The Kort nozzle, used to house the thruster propeller, does more than simply protect the blades. It uses a unique cross section that behaves like an aircraft wing that acts to speed up fluid flow across the inner surface relative to the fluid flow on the outer surface. This shape, along with a slightly tapering inlet cross section, acts to accelerate the flow of water through the nozzle before it even reaches the propeller. The result is a decrease in the amount of work required for the propeller to move the fluid, thus increasing performance and efficiency.

Tether

The tether for our ROV is the bridge between the surface and the ROV that supplies the power, communications, and video feeds. The first revision of the tether consisted of multiple separate wires. This revision contained power and ground lines, communication input and output lines, and two video lines. The power lines transported 12 VDC from the battery to the ROV. Once the power reaches the ROV, it is then regulated and distributed to all of the onboard electronic components. The signal command lines were sent through cat-5 Ethernet cables that were used to transport digital and PWM signals. These signals controlled the thrusters, servos, lights and sensors. Two cat-5 cables were utilized; one dedicated for incoming signals from the surface to the ROV and the other for outgoing signals from ROV to surface. The multi-stranded tether was held together using electrical tape and zip-ties. Floaters were then sized and then applied to the tether to achieve neutral buoyancy. This configuration, however, was not without its downfalls. The tether was too "rigid and heavy" and propagated too much drag to the ROV. Also, unshielded wires that carried digital signals ran down the tether directly adjacent to the power lines. This culminated in substantial signal interference that caused a twitching byproduct in the servos. The tether was then redesigned into a more robust system. This new revision of the tether is based on commercial tether that consisted of multiple shielded conductor wires encased in yellow nylon sheathing. This tether consists of three 20 gauge copper conductors and three 22 gauge twisted pair cables. The twisted pair cables consist of two conducting wires that are tightly wound together throughout the length of the tether. This twist in the wires cancels out any induced magnetic fields and thus reduces signal interference. The yellow nylon tether supplies power and ground to the microcontroller and servos, signal for the hydrophone, and twisted pair lines for the RS-485 TX/RX signals and the camera video feeds. A separate (white) power line consisting of four conductors is attached to the nylon multi-conductor cable. This white line contains the dedicated power lines for the vertical and horizontal thrusters. Running dedicated power to these components reduces voltage drops experienced across the length of the tether. The nylon sheath floats in water and helps to make the tether neutrally buoyant.

Camera

The vision system for our ROV is of paramount importance because it controls how effectively we can perceive our surroundings, and thus determines how well we can navigate the ROV in confined corridors and manipulate small objects. For this reason, we wanted a vision system that was capable of providing multiple viewing angles at the command of the operator. To accomplish this, we decided to use a camera with servo-actuated rotational abilities. The optimal camera solution for our tasks among those we found, and the one that we adopted, used a steerable security camera with 360° rotational abilities, in the azimuth direction and 90° tilt in elevation, giving the operator hemispherical coverage in the forward direction. This setup is shown in Figure 14.

Figure 14. Main ROV 4" Dome PTZ camera

This camera directional control was wired through the camera control panel and accessed through our PS2 controller's right joystick. This functionality allows for the operator to easily adjust the viewing angle with the thumb toggle. This camera was mounted in the center of the hull in the bow of the ROV, thus having a commanding view of the ROV attitude and its external environment, establishing itself as the main ROV camera. This camera is the primary navigation sensor, adapting rapidly to changing light levels, which can easily be adjusted for viewing both grippers on both port and starboard sides of the ROV. A secondary camera system, consisting of a stationary camera furnished with infrared LEDs, was mounted on top of the ROV and positioned to view the main gripper. The IR LEDs allow the camera to operate in extremely low light levels, effectively providing the camera with night vision capability. This capability is particularly useful in the simulated cave environment.

Figure 15. Stationary Camera with inferred capabilities

The secondary camera was very critical in manipulating objects due to the fact that it allows for a clear perspective of the primary gripper and its reachable workspace in any light level. A picture of both the mounted cameras is shown in Figure 16. With this vision capability, the operator can navigate up to an obstacle while using the primary camera and then use the secondary camera for object manipulation.

Figure 16. Mounted Primary and Secondary Camera Systems

An added benefit for the primary camera being a security camera; it has the capability to operate in a minimum light rating of only 1.5 lumens with a 420 TVL resolution. In the original design of the ROV, the Primary pan-tilt-zoom (PTZ) camera shared a power line with the rest of the ROV components.

The drawback of this design was apparent when the thrusters were turned on full power; the induced voltage drop caused temporary video feed blackout. This has been corrected in later design modifications.

Lights

For the lighting system, we wanted to design a system that would give the operator ample lighting when exploring the cave during task #2. The ROV houses two powerful MR11 white LED's that are mounted as end caps for the thruster housings on each side of ROV minimizing shadow blanking. The LEDs themselves are housed in custom machined aluminum fittings that consist of a two piece system that is threaded together to provide easy installation and replacement of the LED bulbs if required.

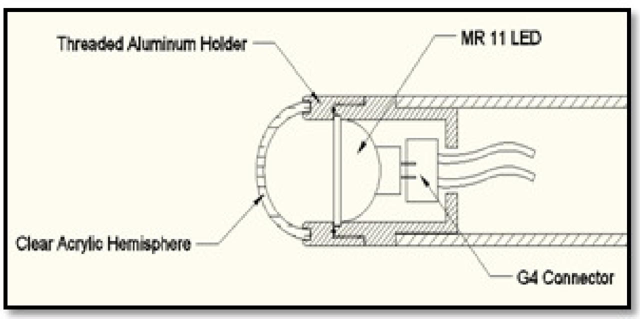

Figure 17. LED Housing Configuration

Figure 18. Actual mounted Lighting system

The MR11 LED's are capable of emitting 240 lumens each and have a combined current draw of only 60 milliamps at 12 VDC. For control of the lights, transistors were used to switch on and off the lights. The digital signal for the LED control transistor was activated by the surface controller board and signaled via pushbutton on the PS2 controller.

Sensors

Hydrophone

The ROV is equipped with multiple sensors that will be utilized to complete tasks 1 and 3. Along with the camera, used as a visual and navigation sensor, the ROV will have a hydrophone as an audible sensor. This hydrophone was custom made by using a microphone element from RadioShack. Custom aluminum housing was manufactured to house the microphone element while simultaneously providing both noise reduction and directionality Latex sheathing and silicone was used to seal and waterproof the microphone from water ingress. Next, the aluminum hydrophone housing was attached to the ROV hull on a piece of Delrin plastic that was machined to act as a mount that resembled a pitot-static tube. This contraption, shown below in Figure 19, was bolted to the hull of the ROV in between the pontoons. The pontoons provided extra directionality for the hydrophone.

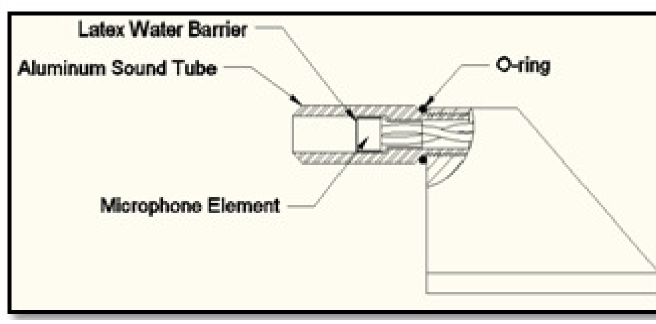

Figure 19. Hydrophone Housing Assembly

Figure 20. Actual Hydrophone Assembly

The electrical power for the hydrophone comes from the 12 VDC power in the yellow nylon tether. This voltage is stepped down to 5 VDC through a uniform voltage regulator on the Arduino board. The signal is then transmitted through the tether and then amplified through TV speakers on the surfac. The hydrophone is fitted with a control transistor and can be turned on and off with the surface controls via pushbutton on the PS2 controller.

Temperature Sensor

Next, a temperature sensor was retrofitted with the ROV to be primarily used in Task #3. The temperature sensor that was used is the LM335A analog temperature sensor. It is a thermistor-bead type sensor that has proven quite stable electronically. Originally the sensor was waterproofed using liquid electrical tape. The design has since then been upgraded. A miniature aluminum contact was manufactured and incased in epoxy resin, along with the sensor. The resin keeps the sensor water tight and the aluminum contact acts as a thermal conductor for accurate temperature readings.

Grippers

We designed two grippers for our submarine. The main gripper has a moving wrist and specially designed fingers. The secondary gripper is meant to pick up specially made parts. This gripper is meant for grasping the crustacean container and the core sampler. The fingers close to form a circle that fits perfectly in a double-sided lip that we made on our container and core sampler. To make the gripper, it was first designed in NX Ideas (CAD and CAM software) and then cut out with the CNC milling machine.

Figure 21. Secondary Gripper

As seen in Figure 21, when the center is pushed forward and pulled back, the fingers open and close respectively. The advantage of this comes into play when the gripper is used to grab an object; when the back of the fingers touch the object that needs to be picked up, it will grasp it without any binding. To move the gripper, a couple options were explored. The first was to use a rotational servo and waterproof it. The servo was used to push on a rod that was connected to the gripper. This method work decently but it quickly became evident that the servo was being used very inefficiently. As a result, it had a very low clamping force. The second method was to use a linear actuator. We found linear actuators from Firgelli that are controlled like a servo. They require power, ground and a signal for position. After testing the new system, the linear actuator worked perfectly. It has a very large back drive force, which is the force required to move it when it is energized and stopped. The linear actuator was housed in a small pipe and sealed up to the end of the housing. At the end of the housing a bellow was attached and sealed. The other end of the bellow was attached to the end of the linear actuator rod and sealed. The actuator was attached to a small Delrin rod, which was threaded at the other end and screwed into the gripper. The sealed housing was fitted into cylindrical pieces made of Delrin that fit snugly inside the pontoons. Two of these cylindrical pieces were used to support the gripper and actuator. This also ensured that the ballast system could not come in contact with the wires so that they could never be damaged.

The main gripper was also designed using Ideas CAD software and machined with the CNC. It was designed around two brushless very high torque servos. This gripper is a two-axis gripper that has 2-degrees of motion: the wrist and the fingers. The servos are wired independently of each other. A picture of a semi-exploded view of the gripper is shown in Figure 22 below.

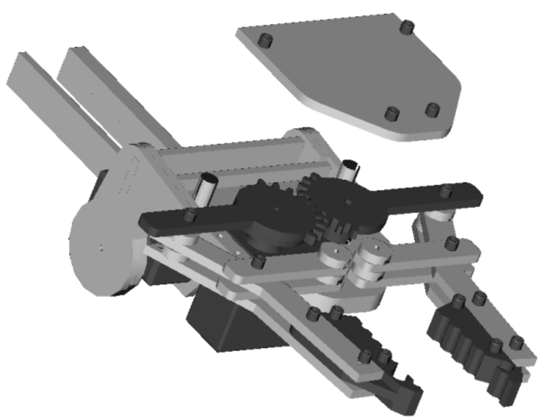

Figure 22. Gripper – Semi Exploded View

The wrist is supported completely by the servo. The servo has an axle built behind it so that the opposite side can be supported as well. The design allows for the wrist to move beyond the limits of the servo. We designed it this way so that the fingers can point straight down and allow the ROV to easily pickup things off the floor. When driving the sub at fast speeds the wrist can be tilted up or down to help pitch the ROV to aid in elevation control.
The fingers are driven by a direct gear system. One gear is attached directly to the second servo and the other is a supporting idler gear. The driving gear moves the left side finger and the idler drives the right side finger. The teeth on the gears were drawn with the proper convolute shape to ensure that there is minimal play and smooth motion. The gears have arms built into them to aid in leverage to close the fingers. The design allows for very efficient use of the servo's torque. The finger can grip hard enough to strip the servo horn so care has to be taken when closing the fingers. The fingers have a slot cut into them so that it can hook onto small rods easily. The rest of the fingers are jagged to help grip objects securely. The fingers of the main gripper are designed so that they can easily manipulate the PVC objects used in the competition. The gripper fingers encase the PVC and act as a 'grapple' for easy manipulation.

The two servos were waterproofed so they can operate easily under water without any problems.

Control System

Two Arduino Mega boards are used to control the ROV. One is located at the control station and the other is located inside the back of the ROV. The UNF ROV was designed be portable so that it could be easily setup and launched from any boat. To accomplish this, the control station also needed to be portable, thus it was made so that it could be quickly assembled and disassembled. This was accomplished by modifying an aluminum case to house the control shack circuitry.

Figure 23. Control Station for Main Camera

The case, shown above, has a RJ-45, RCA video input, 3.5mm headphone jack, 12V DC power input, a Playstation female connector input and an AC power input for the built-in monitor. The monitor is a Dell LCD monitor with a RCA to VGA convertor attached to it. The Arduino Mega inside the box takes in the serial input from the Playstation 2 controller, adds an address byte to it and then transmits it to the Maxim 489E transceiver. This transceiver converts the serial signal into a RS-485 twisted pair signal, which is connected to the tether. The transceiver is a full duplex chip meaning that it transmits and receives simultaneously. This increases the speed at which signals are transferred because simultaneous commands can be sent down the tether. The Arduino also sends another serial signal to the transceiver to control the PTZ camera on the submarine. This is the reason for the address byte at the beginning of the serial signal. The serial lines are connected to the camera through another Maxim chip onboard the ROV. The camera and other Arduino Mega use this address byte to distinguish between which signals they are supposed to process. An overall signal flow diagram is shown in Figure 24.

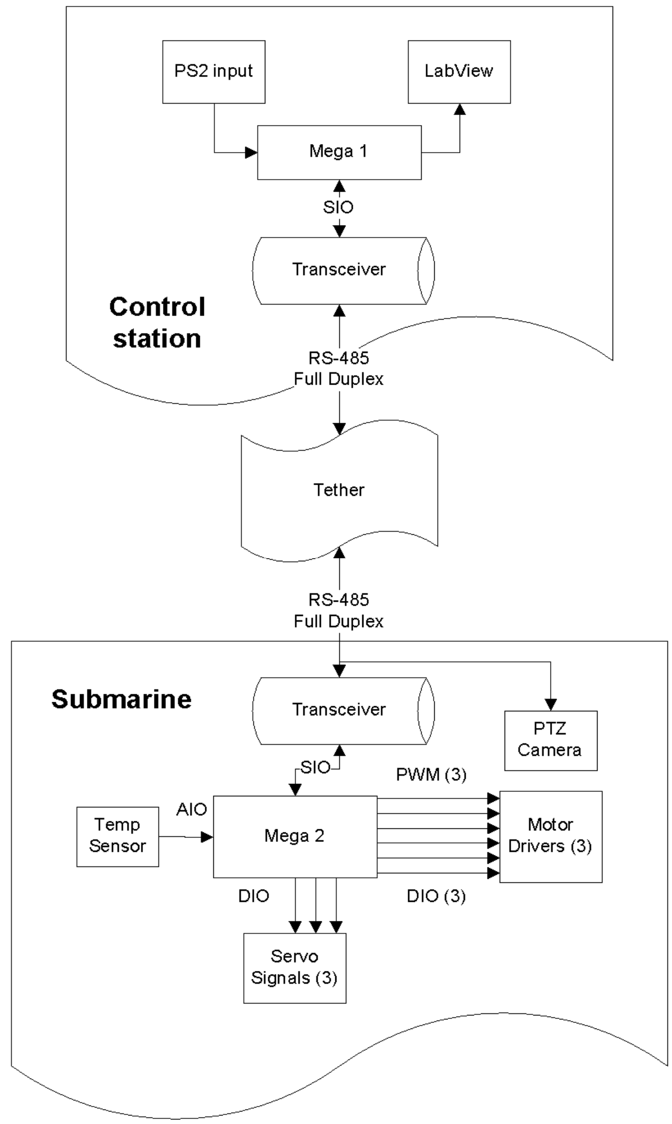

Figure 24 Overall Signal flow

The on board controls consist of three Pololu motor drivers, an Arduino Mega, three 6V voltage regulators, one 5V voltage regulator and a Maxim 489 transceiver. The Maxim transceiver takes the RS-485 signal from the tether and converts it to a standard 5V serial signal, which is sent to the Mega. If the address byte for the signal is 02 then the Mega will process the rest of the bytes. These bytes contain all the information needed to control the submarine except for the PTZ camera. The Mega then updates the PWM values that control the speed of the thrusters. It also updates the DIO values that control the direction of the thrusters. These two signals are then routed to the motor drivers that are connected to the thrusters. The Mega also sends signals to update the position of the servos. It also sends digital signals to turn the power on/off for various devices onboard the ROV i.e. lights, servos, hydrophone and temperature sensor. After the Arduino board updates its values and sends the signals it will then build a byte array of the data that the control shack board requested and serially transmit it to the transceiver and back up the tether. A flow chart for the software is shown in Figure 25.

Our first design for the controls was to send all the signals to control the motor drivers and servos down the tether digitally. We only had one processor and it was housed at the control shack. We had success with this system but soon found that we were getting interference with our signals. It was only noticeable with the servos, which would twitch randomly. The other problem we were experiencing were voltage drops in the power lines. We tried to use a large gauge wire and run all the current down it. Unfortunately, when the motors were running at 100 percent, the induced voltage drop caused video signal blackout because the voltage supplied to the camera temporarily dropped below 12V. To fix this, we used smaller gauges and ran dedicated power lines for each of our major components. We then measured our current draw for the each system

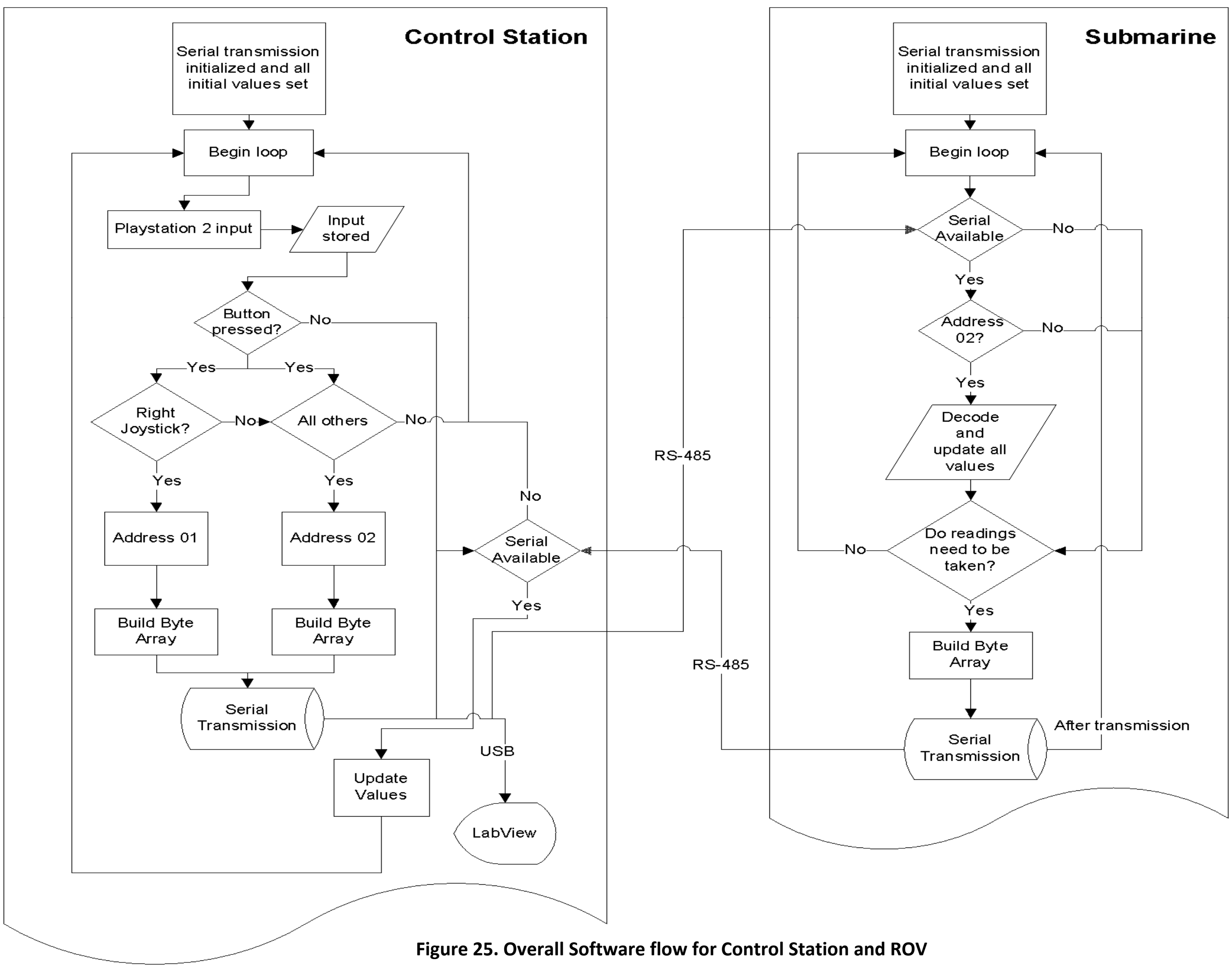

Figure 25. Overall Software flow for Control Station and ROV

component. With this information we were able to separate the current drain across 3 power lines and minimize the voltage drop. This helped ensure that the cameras always have enough voltage to operate and that the motors were always capable of running at max power. The wiring schematic for how this solution, along with the rest of the tether layout, is shown in Figure 26 on the next below

Inside the submarine all of the electronics are mounted on a custom made piece of plexiglass. The circuit boards have risers that keep them from touching the surface of the plexiglass. All of the transistors and voltage regulators are mounted and soldered to a perforated board that have screw terminals that provide easy connection ports for the individual components to receive power. The screw terminals add for ease of maintenance. The plexiglass sheet and mounts were designed to be rigid so that the ROV can be transported easily without having to worry about wires coming loose.

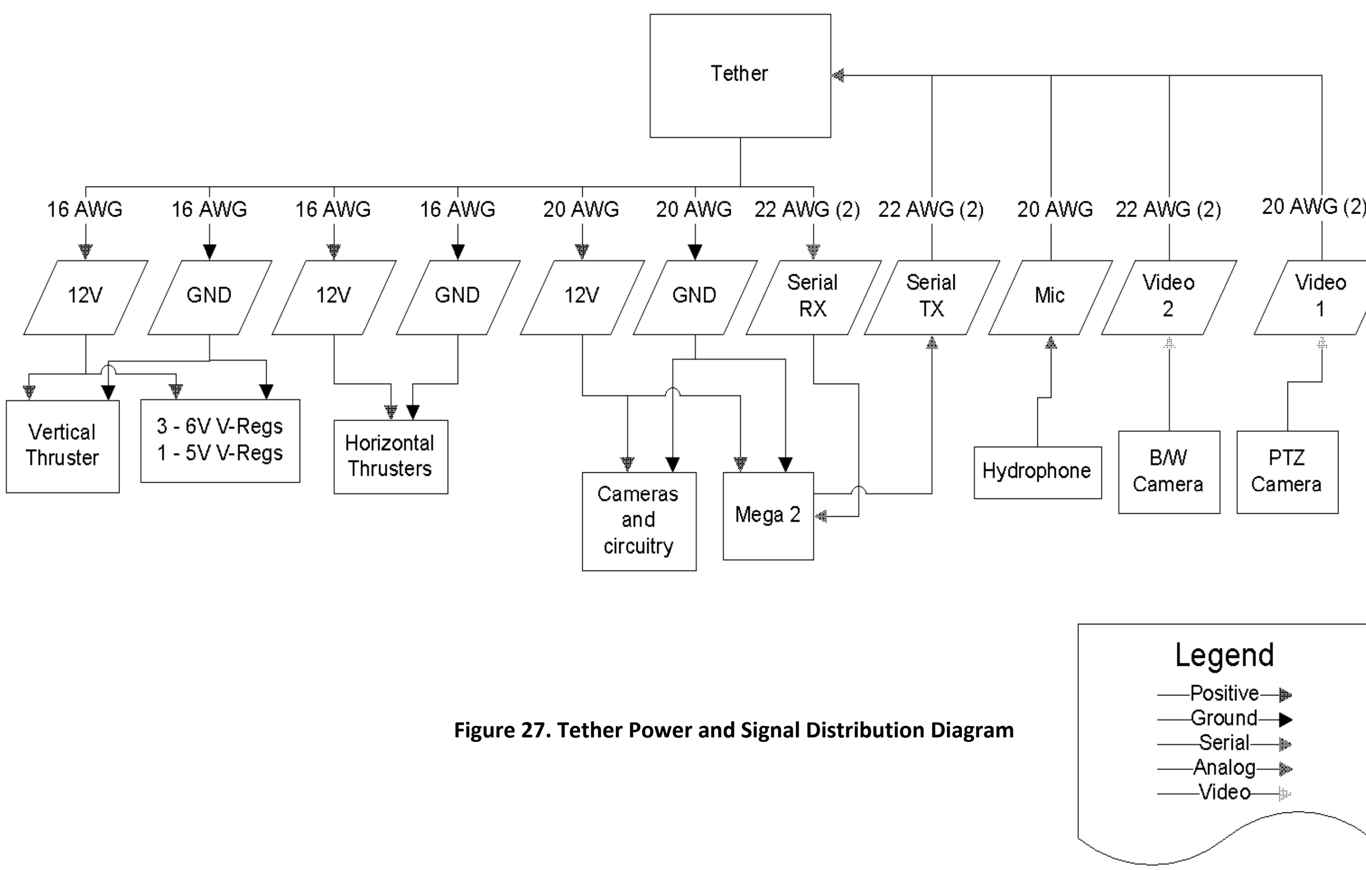

Figure 27. Tether Power and Signal Distribution Diagram

Troubleshooting Techniques

During the laborious journey that we have undertaken while developing this ROV, we have thoroughly exercised our mechanical and electrical troubleshooting skills. There is a particular scenario of equipment failure that staunchly tested these skills.

Moments before we were scheduled to perform at the regional competition, we experienced a complete system failure in our secondary gripper! This caught us off guard as we had just tested the system hours before. We quickly went into overdrive mode and scrambled to grab our multi-meters and emergency box of spare parts. First we checked the micro-controller code for correctness and then reloaded it on the board. Next we tested for mechanical failure by testing the linkage in the gripper for functionality and also for any seizes in the joints. The gripper linkage itself moved fine and was not seized. Next, we exposed to power lines and used the multi-meter to test if the gripper was receiving power. It was. We then proceeded to test to see if the gears in the rotational servo had seized from the sealing used to waterproof them. After passing that test, we then used the multi-meter to test continuity of the single wire from the ROV through the tether to the surface. With another passed test, we were completely dumbfounded on the reason for this failure. We were left with no choice but to compete in the competition with a downed gripper. Fortunately we were still able to surpass our closest competitor and secure our spot in the international competition. It was not until we were back in the lab after the competition that we discovered the reason for this malfunction. After closer inspection and complete disassemble of the gripper, we noticed that one of the tiny connector pins in the male quick-disconnect had been knocked loose. After a sigh of relief and a quick laugh, we decided to forego the use of quick-disconnects and use more reliable waterproof connectors from McMaster to ensure continuity while still maintaining easy removal and replacement if needed.

Challenges

Although every aspect of this ROV had its own unique challenges, one aspect undoubtedly proved to be the toughest challenge to overcome. This aspect was the art of waterproofing servos for rigorous underwater use. As a team, we have been battling this issue since day one. We have gone through many failed attempts, many wasted man hours and lots of money spent on servos that were continuously destroyed through this painfully iterative process of textbook engineering and real world scenarios.

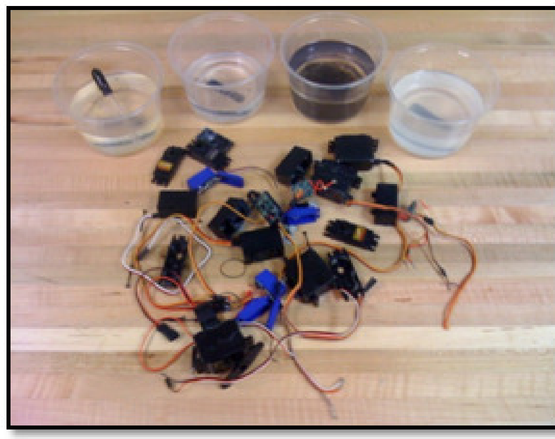

Figure 28. Servo Graveyard

In the early stages, we were using rotational servos with brushed motors. We took apart the servos and tried numerous ways of sealing both the electronics compartment and the gearbox of the servos. For the electronic housings, we tried using a thin layer of silicone brushed on the circuit board, filling the entire housing in silicone and using a thin layer of liquid electrical tape on the circuit board and filling the rest of the housing with mineral oil. For the gearbox, we primarily bounced around using mineral oil, silicone and oil and no oil at all. In each case, we sealed the servo horn shaft with a rubber O-ring. All of these ideas were implemented in the servo in all possible combinations. Every servo we tried eventually failed. Some failed immediately after waterproofing, some lasted a couple of hours and some even lasted a few days before failing. Luckily, we had servos that lasted during the regional competition before failing a few days later. When we packed the silicone in the electrical housing, it caused some parts of the silicone to remain uncured. We learned quickly that uncured silicone is electrically conductive as it shorted out many of our servos. This is the reason for the immediate blow-out of the servos. We also learned that using liquid electrical tape and mineral oil is a bad idea because of the fact that the electrical tape degrades in the presence of mineral oil. We also encountered problems when flooding the servo with mineral oil; it would cause the brushed motor to eventually seize. This explains the phenomenon of servos lasting for a short time before dying. Another reason for the frailty of these servos was the fact that they were relatively cheaply made servos, usually ranging from $12-$35. We are proud to say that, recently, we have finally found a solution to this indomitable problem. We are using substantially more expensive brush-less motor rotational servos from Futaba. We also found the perfect way for us to waterproof them. We first coated the circuit board in a thin layer of silicone and let it cure completely. Then we re-assembled the entire servo while submersed in a bath of mineral oil. The output shaft was fitted with an o-ring and servo horn was then tightened down, compressing the o-ring. This assured that a tight fit that reduced ingress of water. After assembly, we kept the servo submersed in the oil bath and ran the servo through its operating points for 30 minutes. This ensures that all of the air is pushed out of the servo and that the oil compensation process is completed.

Figure 29. Nick Waterproofs a Servo in a Mineral Oil Bath

At this point, we removed the servo, dried the servo and mounted it on the gripper. At this point, the waterproofing process is complete. We have logged several hours so far over the span of a week and have experienced no problems or reduction in performance from the new servos.

Lessons Learned

As a first year team in this competition, we encountered numerous difficulties and have learned many valuable lessons. We have learned to adapt and conquer with the limited resources that we were initially provided. With are relatively small team of three students, we were greatly disadvantaged with lack of man-power. However, we compensated by spending many late nights, and the occasional all-nighter, designing and constructing. We are mechanical engineering students and have a background in fluid-mechanics, strength of materials and manufacturing techniques. While we not quite as familiar with the electronic and controls aspect of the ROV, we quickly learned and extended our academic knowledge across disciplines as we familiarized ourselves with electronic circuits, digital signals, micro-processors and programming in C++. This accomplishment has turned us into, not only well-rounded engineers, but also well-rounded individuals as well.

Another important lesson learned is the fact that "what is designed on paper does not always work in reality". We learned this in several occasions with the first being the hull design. Initially our hull was too long and massive. The amount of weight required to keep the sub neutrally buoyant put too much of a load on our propulsion system. This was counteracted with a smaller hull design; however, the second hull was too small to fit all of our electronic components. We then went with a happy medium, designing a hull that accommodated the perfect balance of weight and interior volume. We also went through multiple iterations with our gripper. Our first gripper was designed separately from the sub. The problem with this was evident when the gripper was completed and ready to be installed on the ROV. The gripper (gripper + arm + elbow) was over half the size of the sub and drastically too big for the ROV! The second gripper was designed with a pushrod actuator connected to a rotational servo. This design was terribly inefficient underwater and was redesigned into the final design of a direct-gear gripper that provided greater torque.

Another major lesson learned was that no matter how hard you try, like sand in the beach, water will find its way in placed you don't want it. We learned a hundred ways not to waterproof a servo, and only one way that worked…for now at least.

Finally, our most important lesson learned is to always remember to have fun in your work and that an Engineer's job is never finished!

Future Improvements

Next year the University of North Florida will be competing in the Explorer class, for the first time, and will therefore need to make some major modifications. The first and foremost is re-enforce the hull and all of the seals to handle to pressures of being 40ft underwater. Secondly, we will need to upgrade our controls to run off of 48volts rather than 12. We strongly view this as an advantage as we found it very difficult overcome the voltage drop across the tether and still power all of our thrusters and onboard components at once.

Other future improvements that we plan to implement include adding an adjustable ballast system in the pontoons. The system would consist of a movable weight system that can be directed to the front or back of the pontoons to adjust the pitch of the ROV and aid in diving and surfacing. The ballast system could also offset the weight of heavy objects picked up by the grippers. The ballast system would be controlled by stepper motors that are controlled by the surface controls.

A final design improvement would be to digitize our audio signal from the hydrophone and video signal from the cameras. This would greatly reduce the amount of noise and signal interference as these signals traverses the tether and get processed on the surface.

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Appendix – Budget

Website	Part #	Unit Price	Quantity	Ext
Mouser.com	Adjustable Voltage Regulator	$6.15	5	$30.75
SparkFun.com	15A Motor Driver	$39.95	3	$119.85
SparkFun.com	Screw Terminals (2-Pin)	$0.95	5	$4.75
SparkFun.com	Screw Terminals (3-Pin)	$0.95	5	$4.75
SparkFun.com	Arduino MegaShield Kit	$17.95	2	$35.90
SparkFun.com	USB Cable A to B	$3.95	1	$3.95
SparkFun.com	USB Cable Extension	$4.95	1	$4.95
SparkFun.com	Standoffs Plastic Short	$1.95	4	$7.80
SparkFun.com	Temp Sensor LM335A	$1.50	3	$4.50
SparkFun.com	Arduino Mega	$64.95	2	$129.90
outdoorspeakerdepot.com	100 Ft 16 AWGx4	$39.95	1	$39.95
mcmaster.com	PCB Mounting Bolts	$4.31	1	$4.31
mcmaster.com	PCB Nuts	$2.77	1	$2.77
mcmaster.com	Pontoon bolts	$7.41	1	$7.41
mcmaster.com	4 flute end mill 1/32	$13.38	3	$40.14
mcmaster.com	Pontoon mount Al	$66.25	1	$66.25
mcmaster.com	Tail Cone Al	$18.29	1	$18.29
mcmaster.com	Motor Mount Al	$42.39	1	$42.39
mcmaster.com	Delrin for end caps	$180.01	1	$180.01
mcmaster.com	Pins	$8.72	1	$8.72
mcmaster.com	Sockets	$9.38	1	$9.38
mcmaster.com	Wire Seals	$6.77	1	$6.77
mcmaster.com	Plug Housing	$10.20	1	$10.20
mcmaster.com	Receptacle Housing	$6.76	1	$6.76
mcmaster.com	Extraction tool	$6.00	1	$6.00
store.firgelli.com	Firgelli Linear Servo	$90.00	3	$270.00
ixbay.com	4" PTZ Camera	$164.00	1	$164.00
westfloridacomponents.com	Microphone Element	$1.25	3	$3.75
kitkraft.biz/home.php	6" Clear dome	$11.95	1	$11.95
kitkraft.biz/home.php	1-3/4" Clear domes	$6.95	1	$6.95
ebay.com	12V MR11 Led Lights	$9.50	2	$19.00
ebay.com	Futaba Brushless Servo	$179.99	2	$359.98
homedepot.com	3" Sch 40 PVC	$9.92	1	$9.92
homedepot.com	4" Sch 40 PVC	$13.46	1	$13.46
homedepot.com	6" Sch 40 PVC	$17.89	1	$17.89
homedepot.com	1.5" Sch40 PVC	$3.71	1	$3.71
rocketcityracing.com	1/4" Shaft and Dog drive	$10.00	3	$30.00
applied.com	1/4" Shaft Lift Seals	$16.66	3	$49.98
surveillance-video.com	Speco BW Waterproof Camera	$139.58	1	$139.58
amazon.com	100ft Video/Power cable	$17.97	1	$17.97
VideoRay	100mm propellers	$50.00	3	$150.00
		Total	**$1777.06**	

Appendix – Acknowledgements

The University of North Florida "Blue Ray" ROV team would like to thank the following companies and organizations for their contributions to making the university's very first ROV a success. Without your donations, none of this would have been able to come together. We appreciate your support of our project and our education. THANK YOU!

Company/Organization	***Donation***
Taylor Engineering	$2,500.00
UNF Engineering Advisory Council	$1,000.00
Haskell Engineering	$500.00
Florida Engineering Foundation Inc	$1,000.00
Don Farshing	$50.00
UNF College of Computing and Engineering	$2,400.00
SolidWorks	CAD Software
Total	$7,450.00