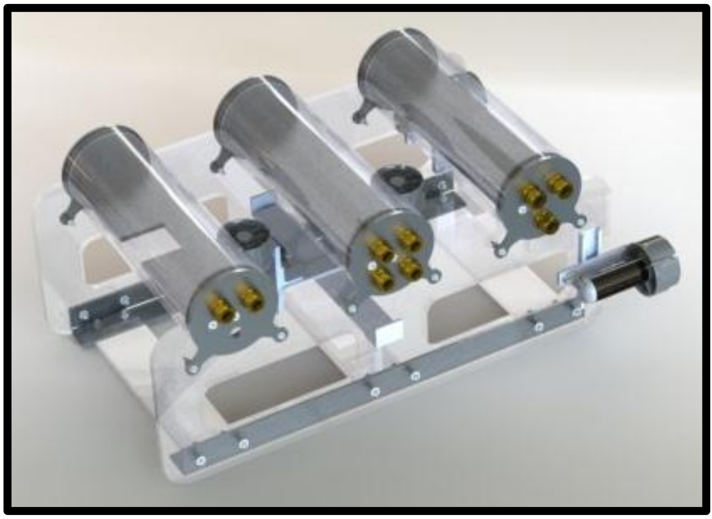
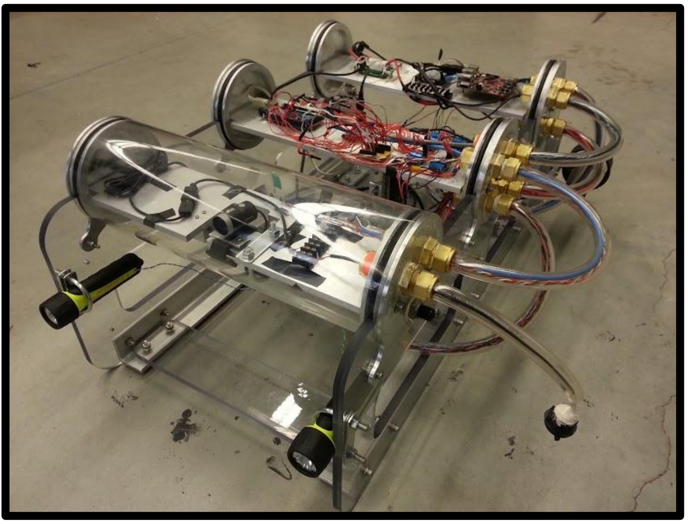
TECH 797 Final Report

UNH
Aquacats
Underwater
Remotely Operated Vehicle





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Contents

Table of Figures

Introduction

Abstract

An underwater Remotely Operated Vehicle (ROV) was designed, built, and tested for 2013's UNH ROV team. UNH ROV is an interdisciplinary senior design project team that focuses on building a ROV for competition and research based aspects. This year's ROV team has built a ROV that will compete in the Marine Advanced Technology Education (MATE) competition that will be held in Seattle, Washington on June, 20 2013. The ROV will also be used in a graduate research project where two ROVs will be controlled in a leader-follower type fashion to perform tasks underwater.

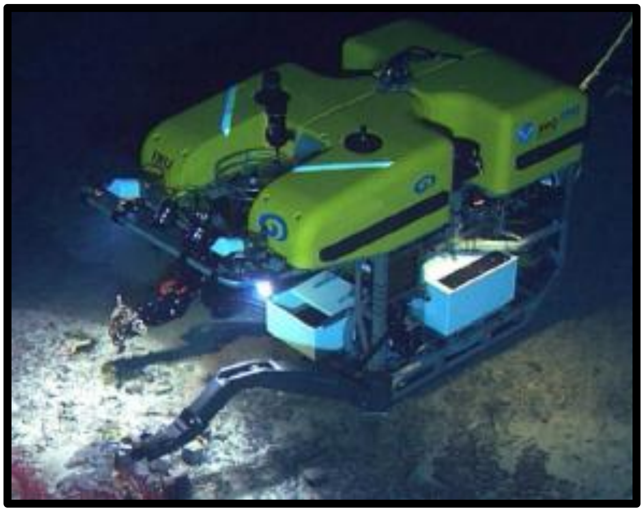


Figure 1: Commercial underwater ROV exploring the sea floor.

Background

Underwater Remotely Operated Vehicles (ROVs) are an intricate aspect of current underwater exploration. They are capable of reaching places underwater that would be either too hazardous for humans to explore or too expensive due to the physical and technical limitations of building manned underwater vessels. ROVs are characterized through their tether which is connected to a receiver on land or on a ship. The tether of the ROV provides electricity to power the vehicle and data transmission for communications and controls. The operator of an ROV resides out of harm's way on the surface of the water while the ROV does the work below. Thrusters are used to maneuver the ROV underwater and orient it in the way the operator would like. ROV's relay most of their surrounding information to the surface from cameras on and around the ROV. With video feed from the ROV it is possible to perform tasks underwater such as repair work. ROVs can be equipped with specific tools such as mechanical arms to complete jobs underwater that divers or manned submersibles cannot perform. To perform tasks adequately underwater, ROV pilots rely on the camera systems, robotic appendages, and highly maneuverable electric propulsion systems to control the ROV.

The University of New Hampshire (UNH) is a large supporter of marine sciences and engineering through their Chase Ocean Engineering facility. UNH receives funding as a Sea Grant School and uses that money to fund marine science senior design projects. UNH ROV is associated with the Marine Advanced Technology Education (MATE) Center that deals with further understanding the marine sciences. MATE organizes a yearly international intercollegiate competition that UNH ROV has participated in since 2008.

Previous year's ROV teams have all competed at the yearly MATE competitions and done well at each event. Most of the previous teams had given themselves their own name to associate themselves with at the MATE competition. The first two teams used the name SEACATS and the most recent team changed the name to UNH ROV, and this year's team is the UNH AQUACATS. Each year MATE organizes new mission tasks for the competition, this year's MATE competition simulates the maintenance of undersea scientific equipment off the coast of Seattle, Washington. This year's ROV has been designed to be modular to be able to complete the underwater tasks in the competition. This year's UNH ROV team has been assembled to design, build, and test our own ROV and compete with it in the 2013 MATE competition and also to be able to aid in graduate research in leader-follower ROV design.

Introduction

This year's ROV team has set a list of goals to accomplish in order to create a ROV that can be used in both competition and research based aspects.

- To design, build, and test a fully functioning ROV
- To compete in the international MATE ROV competition in Seattle, Washington
- To build a modular test platform that can be used for graduate research for leader-follower ROVs

To accomplish the goals, this year's team was divided into three subgroups: Chassis, Propulsion, and Controls. The subgroups were chosen based off of three critical aspects of creating a functioning ROV. Chassis would create the frame of the ROV and provide housing for the electronics. Propulsion would be in charge of producing the necessary thrusters to move the ROV underwater. Controls would be in charge of controlling the ROV and creating the necessary graphical user interface (GUI) for easy use. Efforts were made to ensure constant communication between the subgroups in order to create an integrated design. Modularity, expandability, and functionality were highly emphasized by all subgroups.

Some complex ROV components were purchased fully assembled while all other components were fabricated from stock materials, either at UNH by members of the ROV team or by professionals. The cost of constructing the ROV was significantly reduced by building, instead of buying most of the ROV's components.

Separately testing individual parts of the ROV was extremely important to test waterproof seals. If any water were to breach the seals of the ROV, the internal electronics would be destroyed.

UNH Aquacat Overview

The 2013 ROV has three main components, 3 O-ring sealed tubes and the electronics they contain, 4 thrusters to move the ROV in the water, and a frame to hold these components together.

The chassis of the ROV was designed with 3 main goals in mind. The first goal was to be modular, with an abundance of open space to allow for additional components to be attached in the future. Specifically, a grasping mechanical arm is currently being designed to grab and drop external objects. Second, the chassis was designed to be stable underwater by positioning the ROV's center of buoyancy directly above the ROV's center of gravity. This allows the ROV to orient itself correctly without the use of thrusters to control pitch and roll. The third design goal of the chassis was for it to be slightly positively buoyant, so that in the case of power loss onboard the ROV, the ROV would float to the surface and be easier to retrieve.

To allow the ROV pilot to see where they are going and what they are working on, the ROV is equipped with an HD webcam in the front electronics tube. This webcam is attached to a servo motor, allowing the ROV pilot to pan the camera up and down, to center objects of interest in the camera's field of view.

To move in the water, the ROV is equipped with 4 thrusters, two oriented vertically in the center of the ROV, to move the ROV up and down in the water, and two oriented horizontally in the rear of the ROV, to allow the ROV to move forward, backwards, and yaw from left to right. These particular thrusters were chosen because they are relatively easy to control, consume relatively low amounts of power for the thrust they produce, and include a cowling, which reduces inefficiencies, adding to the generated thrust.

The ROV relies on numerous electronics to allow communication between the pilot and the onboard components and thrusters in order to accomplish the chosen tasks. A graphical user interface is installed on an onshore laptop which is used to communicate with the ROV. The laptop communicates directly with the onboard camera, and the onboard Beagleboard. The Beagleboard is a miniature but fully functional computer which acts as a stepping stone between the Arduino microcontroller and the laptop. The Beagleboard powers the Arduino, receives user defined motor commands and relays them to the Arduino, and collects sensor data from the Arduino and intertial measurement unit (IMU), which collects orientation data, and communicates it to the laptop. The Arduino receives high level motor commands from the Beagleboard and translates them into pulse-width-modulation signals which are then sent to the 4 motor drivers, which power the thrusters. The Arduino also receives low level voltage signals from the internal temperature, internal humidity, and external pressure sensors, and relays them to the Beagleboard.

The tether physically connects the ROV to the surface, and is comprised of three cables which transmit power from a battery bank, data from the Beagleboard to the laptop, and video from the webcam to the laptop. The tether is 60 ft long and is designed to be neutrally buoyant to reduce its drag on the ROV.

Power is stored in an onshore battery bank, which is connected to a fuse box to prevent extensive electrical damage to the ROV. The fuse box is connected to the ROV via copper wires within the tether.

Data is transmitted from the ROV to the laptop and displayed on the GUI, which displays the ROV sensor data and is used to control the ROV. The GUI collects the sensor data and displays the internal temperature and humidity within each tube for diagnostic purposes, and combines the pressure and IMU data to give ROV depth and orientation. The ROV thrusters and camera servo are controlled by a Playstation 3 controller. The simple design of the GUI allows the ROV to be piloted by relatively inexperienced pilots with little to no instruction. The three main physical components (Electronic tubes, thrusters, and frame) combined with the GUI create a capable and easy to use ROV system.

Mate Competition

This year's UNH ROV team will compete in an international Marine Advanced Technology Education (MATE) competition that will be held in Seattle, Washington on June 20th, 2013. In the competition the ROV will receive points towards its overall score based on its design and how well it can perform tasks underwater.

Real World Problems

The tasks assigned are based off of real world problems that are faced in underwater environments. Off the coast of Seattle, scientists are trying to better understand the ocean by installing sensors on the sea floor. These sensors are connected via cable systems to onshore labs where the thermal, seismic, current, and a variety of other oceanic data are analyzed. Problems arise with installing nodes on the seafloor due to the technical limitations of manned underwater vessels. ROVs allow for the installation and maintenance of these sea floor sensors and cabling, without endangering dive teams. Another real world problem around the Seattle area is monitoring the activity of submarine thermal vents. This can be accomplished by measuring the change in water clarity caused by vent emissions with a transmissometer. Finally, a common problem in undersea environments is the accumulation of bio-fouling, which can interfere with data collection and heat dissapation. Underwater ROVs can be used to remove bio-fouling from underwater surfaces without the need of removing the devices for cleaning. Many of the obstacles faced in the monitoring of oceanic data can be overcome through the use of ROV's.

Simulated Tasks

For this year's MATE competition we will be competing as an Explorer class ROV. The Explorer class part of the competition has four tasks that can be completed by our ROV in order to receive points. These tasks simulate the real world obstacles encountered in the Seattle coastal monitoring program. The first task is installing a sensor node on the sea floor and will be simulated by placing a milk crate inside a cube as seen in Figure 2. The second task includes designing and building a transmissometer as well as placing it next to a simulated underwater thermal vent. The transmissometer must sense the clarity of a rotating disc and relay this data back to the user onshore. The third task is to replace an Acoustic Doppler Current Profiler (ADCP) on a mid-water column mooring platform. This task will be simulated with a mid-water column PVC structure that must be removed and replaced. Once this component is replaced it needs to be leveled out using its adjustable legs. The fourth task is to remove bio-fouling from various parts of undersea structures. This bio-fouling is simulated with simple pipe cleaner loops attached to the PVC structures. All these tasks have been created for the MATE competition to simulate problems encountered while monitoring the seafloor off the coast of Seattle.

Chosen Tasks

In the MATE Explorer class competition, only 15 minutes are allotted to complete the given tasks. Due to this time constraint, the ROV will only be used to attempt parts of 3 out of the 4 tasks: The installation of the milk crate into the PVC cube, the construction and installation of the transmisometer, and removal of bio-fouling. The installation of the milk crate can be completed relatively easily with the use of a mechanical arm. The second task of constructing and installing a transmissometer was chosen due to its ease of completion and high point potential. The removal of bio-fouling will be completed easily with the use of a mechanical arm. We believe once the prior two tasks are completed we will spend the remainder of the time using our mechanical arm to remove as much bio-fouling as possible. By completing these three tasks we believe will be able to score a large amount of points in the competition.

Figure 2: Backbone Interface Assembly PVC construction.

Figure 3: Transmissometer mounting platform without rotating disk.

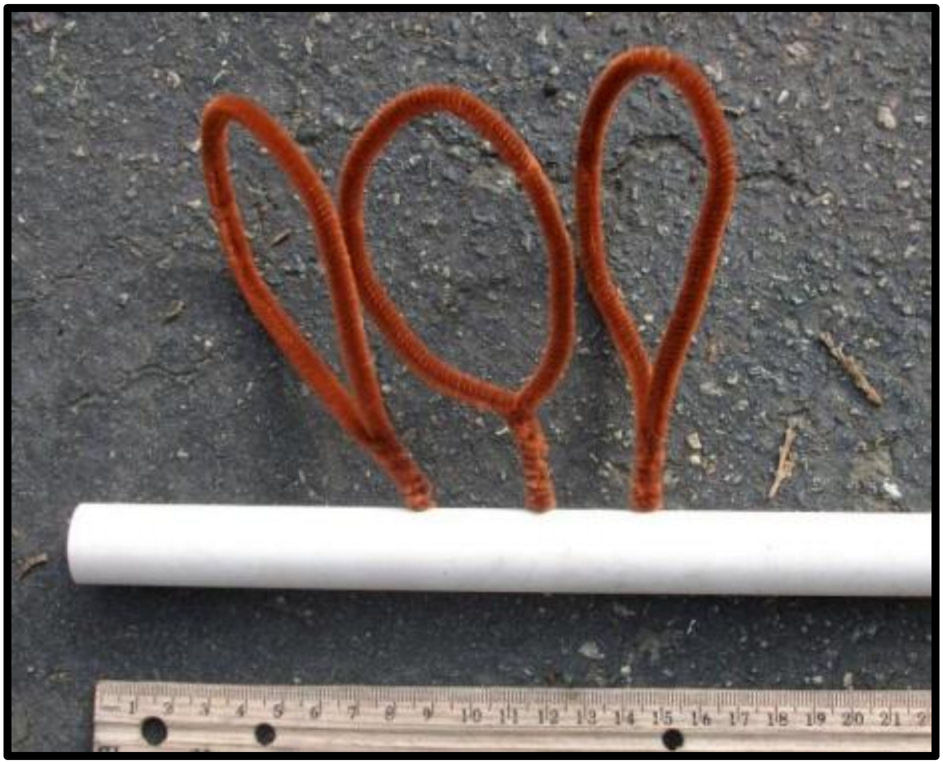


Figure 4: Simulated pipe cleaner bio-fouling.

ROV Systems Design

Chassis

The most important rule when designing the chassis of an ROV is to ensure that the center of gravity of the submersible is below the center of buoyancy. This will prevent the ROV from rolling or pitching, which would make control of the ROV more complicated. The frame structure of the ROV needs to be relatively light-weight, but robust enough to travel and support the necessary hardware. Polycarbonate was chosen because it has a density very close to water, but is still strong and easily machined.

The electrical components need to be inside of a waterproof container, but still be able to communicate with the thrusters. Acrylic tubes were chosen to house the electronics because the circular ends of tubes are easier to waterproof than containers with corners. The first design that was considered was a single electronics tube with a dome on one end to house the camera. Due to the high cost associated with custom ordering such a large tube with a dome and machining limitations at UNH, this design was revised to have two slightly smaller tubes. However, a two tube design would require a box in the middle to house the Inertial Measurement Unit (IMU) which must be placed between the center of boyuancy and center of mass. Boxes are much more difficult to waterproof so they were avoided.

The final design that was decided upon has three electronics tubes placed laterally across the submersible so that the ends of the tubes are on the sides of ROV. Each of the three tubes is sealed on both ends by an aluminum end-cap with large Viton Fluoroelastomer O-rings to allow for easy removal and to ensure a water tight seal. The 3 tube design allows for the center tube to house the IMU, Arduino and motor drivers, the back tube to house the beagle board and DC to DC converters, and the front tube to house the camera. Temperature and humidity sensors will also be placed in the tubes to monitor water leaks and overheating of the electronics. The tether will be connected to the back tube, where the components that need to be accessed first are located, so the 3 tube design integrates well into the electronics flow.

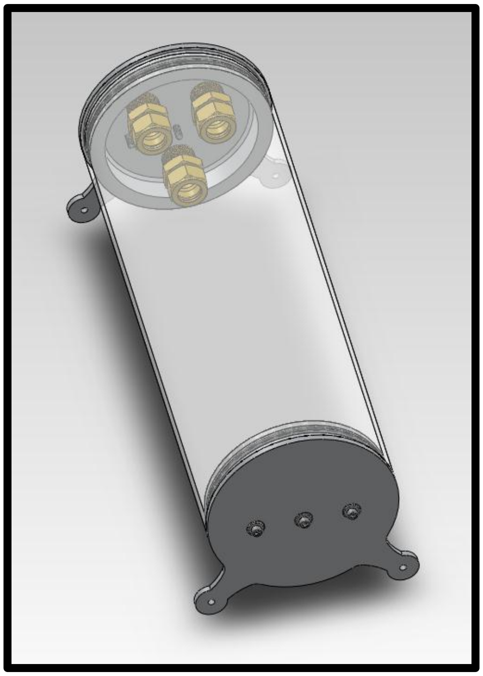


Figure 5: SolidWorks model of electronics tube assembly design.

Wires from the electronics will need to enter and exit the acrylic tubes through the end-caps while maintaining a waterproof seal. This was done through the use of bulkhead fittings with yor-lok compression fittings coupled with flexible plastic tubing which wires will run through.

The ROV was designed to have slight positive buoyancy when fully submerged. In order to achieve this positive buoyancy the dimensions of the ROV's main components would have to be carefully designed. A MatLab code was written to calculate the size of the tubes that would best fit our space requirements for electronics while supplying ample buoyancy to keep the ROV from sinking. Each electronics tube supplies about 18lbs of buoyancy force with the entire ROV designed to have a net buoyant force of 15lbs. This 15lbs is key because of the modular design, additional components, such as the mechanical arm, will be added for the MATE competition. The final buoyancy of the ROV will be fine-tuned by adding weights to the bottom frame; this will increase stability and allow for careful balancing of the ROV.

Weight reduction while maintaining frame rigidity was important so key components such as the electronics tubes and thrusters mounts were designed to take the place of frame members. Instead of having large cross members on top and bottom of the frame, the three lateral electronics tubes were built into the frame to act as the cross bracing support members. The vertical thruster mount was used to stiffen the chassis from rotational torques. By using these components as part of the frame, less polycarbonate could be used and a lighter, more open ROV chassis could be designed.

High temperatures in the electronics tubes could damage the electronical components because many components will malfunction at a certain critical temperature. This could be catastrophic if the pilot lost communication with the ROV while underwater. In order to ensure that the heat generated by the electronics in the tubes would not affect the ROV's performance, a thermal analysis was performed using SolidWorks Simulation. A simplified model of the electronics tube was modeled in SolidWorks, along with the electronic components that will be in the middle tube such as motor drivers and the IMU. A low convection boundary condition of 5 W/m2K was used on the outside of the acrylic tube and on the outside surface of the end-caps because the ROV will not be moving at all times. The outside water temperature (the pool temperature) was set at 27 degrees Celcius or about 300 Kelvin. The four motor controllers were each given a heat generation of 15 W/m^2*K based on the power supplied to them. The IMU was given the same heat generation as the motor drivers even though it is expected to produce less heat. Additionally, the Arduino was given a larger heat generation of 50 W/m^2*K. Because of the relatively small size of the electrical components (a motor driver is less than one square inch) compared to the aluminum cold plate that supports them, the temperature distribution that was calculated by SolidWorks had a maximum temperature of a few degrees above the outside water temperature. This high temperature of 28.6 degrees Celsius is well within the operating range of all the electronics.

The maximum temperature is not much higher than the temperature of the pool because the components are small enough that conduction through the cold plate to the end-caps dissipates much of the generated heat. The other two electronics tubes were not analyzed because they contain less electric components and therefor will not produce as much heat.

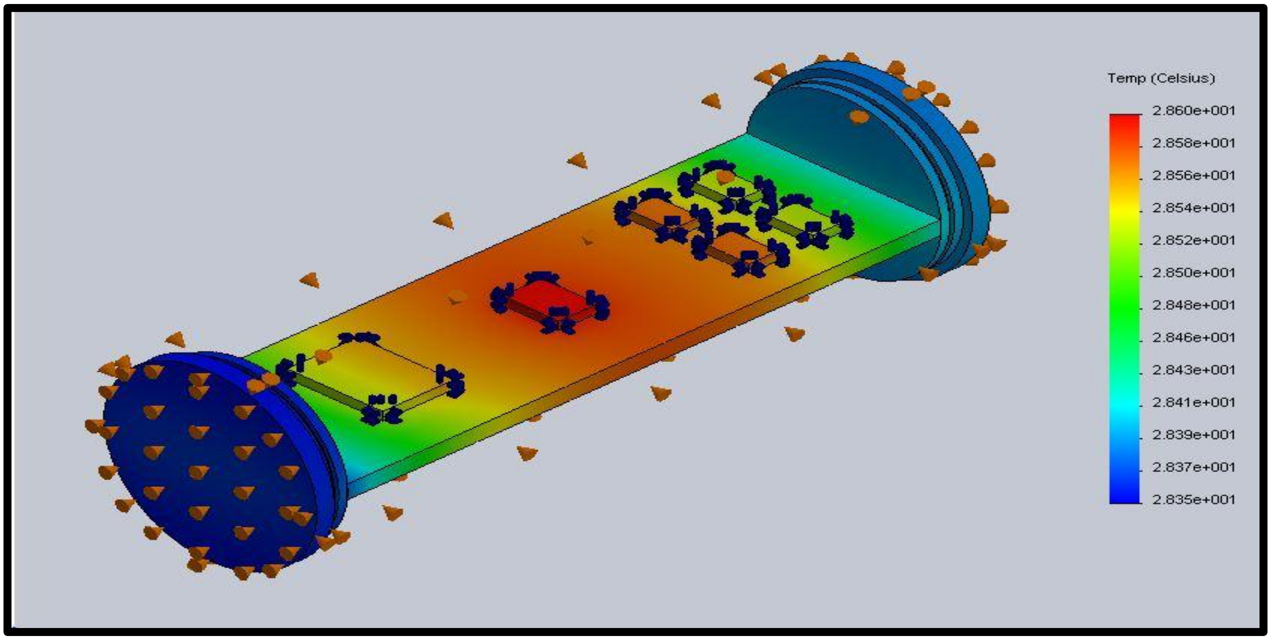


Figure 6: Thermal analysis of simplified tube and end-cap design.

Manipulator Arm

The manipulator arm consists of a waterproof housing, a servo motor, a gear and rack, and an extender claw that is engaged by a pull-string. The servo motor serves as the drive to engage the extender claw by turning the gear. The rack, which is a gear-toothed linear component is mounted to a .25 inch steel rod, and coupled to the gear and servo motor assembly. A dynamic O-ring assembly to prevent water from accessing the servo motor is designed on one face of the housing so that the steel rod can slide forwards and backwards, pulling the string and therefore opening and closing the claw. The servo motor was chosen to apply enough torque so that the claw has the necessary gripping force to pick up any of the components for the MATE objectives. The mechanical arm is still in the design phase as it is not necessary to qualify on May 11th. In between qualification and the regional competition in Seattle, the arm will be constructed and attached to the ROV.

Camera

In order for the pilot to be able to see where the ROV is going and observe the surrounding environment, a camera was placed in the front electronics tube. The camera needed high resolution to ensure that the camera feed is still clear even when underwater, it needed to be small so that it could fit in the 5 3/4 inch inner diameter of the tube, and it also needed to be able to send its video feed through 60 ft of tether up to the surface. 3 different video transmission options were researched, the first being a small security camera attached to a coaxial cable. There were plenty of small security cameras with 60 ft cables that could transmit video but the resolution of these cameras was low. In order to find a security camera with acceptable resolution the cost of that camera became a problem. The second option was to use a high resolution webcam that uses USB to transmit its video feed, the problem with that is USB can only transmit video at lengths of 15 ft or less. To solve this problem a USB to Ethernet converter was used to see if a 100 ft Ethernet cord would be able to transmit the video from the camera to the surface. This USB to Ethernet system could only increase the cable range to around 30 ft which was only half of what was needed. The last option was to use the USB webcam with signal boosters along the USB cable that would increase the range to 60 ft. With the Ethernet option a failure and the security cameras at such a high cost the last option of USB boosters was chosen as the solution. Once the cable solution was determined all that was needed was to find a small camera that would be easy to mount in the tube, which was found to be the Microsoft LifeCam Cinema. It's a 720p resolution camera that is 1 inch diameter cylinder that is 1.81 inches long.

Once the camera was chosen the camera mount was the next step in the design process. The camera needed to be mounted in the front electronics tube and in the center of the width of the ROV. The mount also needed to be able to tilt up and down to give the pilot the option of looking down at the mechanical arm or up at the surface or anything else in the surroundings. To accomplish this, the cold plate in the front tube needed to be milled out to fit the camera and a servo needed to be added to rotate the camera up and down. A mounting system to attach the camera to the servo, as well as stabilize the camera during operation needed to be designed and machined. The design for that mount was a square mounting plate, a motor shaft, stabilization rod, and a stabilization cube. The camera directly connects to the mounting plate, the motor shaft inserts into the side of that plate and connects the plate to the servo motor, and the stabilization rod connects the stabilization cube into the other side of the mounting plate to support the mounting plate from each side.

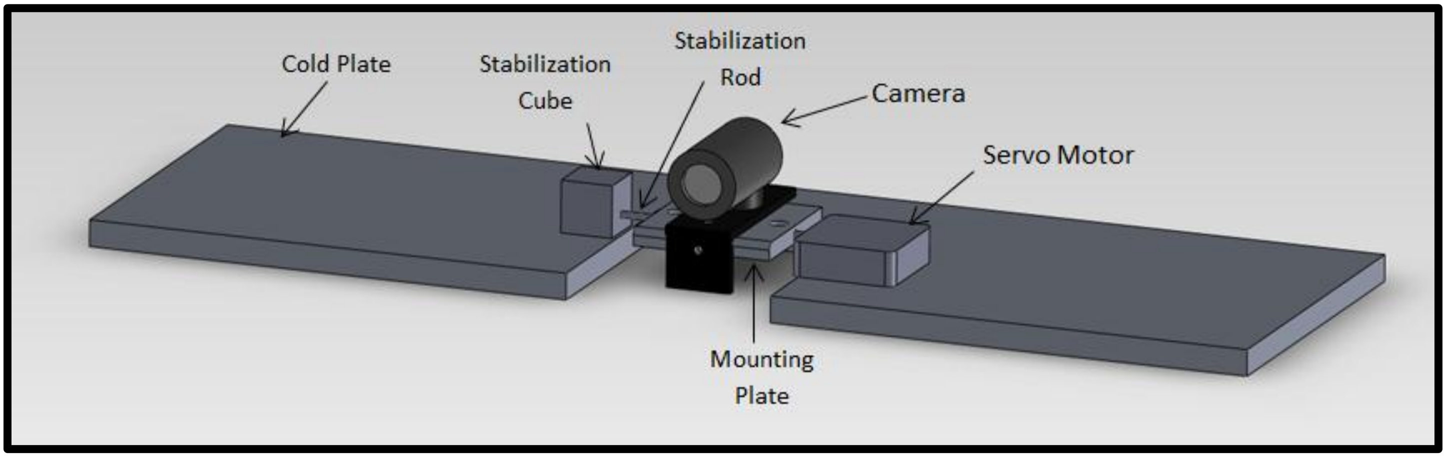


Figure 7: SolidWorks model of camera and camera mount design.

Propulsion System

The first step in designing the propulsion system was determining how many degrees of freedom the ROV would require to complete the chosen mission tasks. The chassis's self stabilization automatically accounts for pitch and roll, and it was determined that left-to-right translational motion would not be required to complete the mission tasks. By removing the requirement of these degrees of freedom, the ROV could function with only 3 thrusters. As seen in THE DIAGRAM BELOW, one additional thruster was added in the up/down direction to help the ROV descend more rapidly.

Once the high-level propulsion system design was determined, the design characteristics of the individual thrusters had to be determined. Ducted propellers driven by an electric motor in a waterproof housing were chosen as the propulsion system thruster design based on their ubiquitous use in industry. The easy to control, and competitive cost of brushed DC motors made them the obvious choice for our thrusters. The addition of a cowling reduces the tip losses of the propeller, directs the flow more effectively, and can add additional thrust output by accelerating the water, and creating lift in the direction of the thrust. As is common in industry a MARIN type 37 kort nozzle was selected for the contour shape of the cowling. Lastly a two bladed propeller was chosen for its high thrust-to-electrical power ratio.

Controls

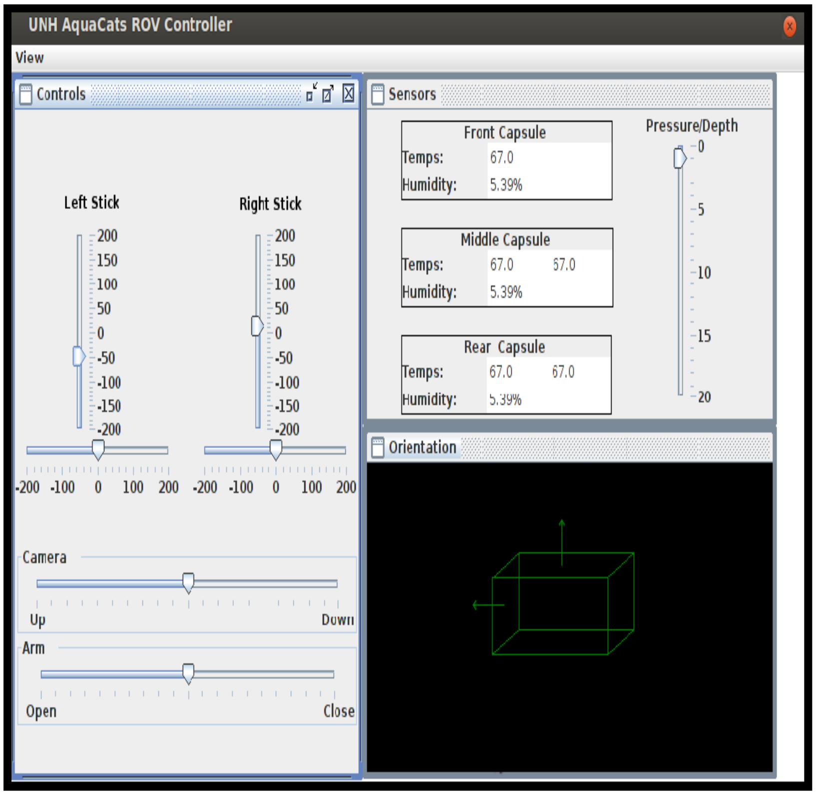
The Design for the ROV's control system is broken into three main parts. The Graphical User Interface, or GUI located on shore on a laptop, the Beagleboard on board computer (OBC), and the Arduino microcontroller and its sensors.

The OBC's job is to act as a relay agent for all data communication between the GUI and the other on board electronics. The OBC runs three different servers that were written using C++, one for handling motor commands, one for sensors information, and another for receiving data from the inertial measurement unit (IMU). The IMU is a collection of sensors including a gyroscope, an accelerometer and a magnetometer that used together can give accurate orientation values. The IMU outputs roll pitch and yaw data in a text string over a serial connection. The OBC reads these using our custom Serial class created using library functions from the C++ boost library. The orientation information is relayed back to the GUI over ethernet. The sensor server works in much the same way, utilizing our Serial class to read text strings coming from the Arduino, and relaying them back over ethernet for processing and display on the GUI. The motors server waits for commands to arrive from the GUI over ethernet. Upon receiving a command, it will relay it over the serial connection with the Arduino, again using our Serial class.

The Arduino microcontroller is responsible for both relaying motor commands to individual thrusters, and collecting sensor data to send back to the user. The Arduino receives motor commands in a three byte format: (Motor Address, Direction, Speed). This format allows all the necessary information to be relayed for the Arduino, while cutting down on the size of the data transmitted. The four thrusters installed on our ROV are each connected to their own pin on the Arduino, this pin correlates to the "Motor Address" field of the command. All thrusters are capable of forward and backward thrust at various speeds. We define the speeds for our motors from 0 to 255 (size of a unsigned byte). The second "Direction" field is used to specify forward or backward speed. With regard to sensor information, the temperature, pressure, and humidity sensors all send voltage values to the Arduino pins they are connected to. These voltage values are placed in text strings with character identifiers before the values for easy parsing on the GUI when they arrive. Like many small embedded systems, the Arduino board functions by calling an Init() function, then repeatedly calling a loop() function. On each execution of the loop function, the serial connection is checked for any control commands waiting to be read. The loop also records a system time and checks it against the last instance of a sensor poll. When the difference in time is 1 second, the sensors are polled for their information, and the text strings are sent back over the serial connection to the OBC. All the Arduino code is written in C++ using the Arduino libraries.

The GUI is the pilot's main interaction point with the ROV. Upon starting the GUI, bash scripts connect to, and initialize all necessary servers on the OBC. When the user opens a sub window of the GUI (Controls/Servers/Orientation etc.) the GUI connects to these servers and data transmission begins. The

Controls section of the GUI allows the user to send motor commands to the thrusters and the servos running the camera and mechanical arm. Sliders are present on the Control window that can be dragged to send desired values to individual motors, however the primary method of control is through the Playstation 3 controller. The Playstation controller provides a much more intuitive interface for the pilot, allowing control of multiple thrusters at the same time. As commands are sent to the ROV from the controller, the sliders on the GUI update to help the pilot determine what speeds they are sending for better feedback and precise control. The design of the control code mimics the design of the chassis in that it is modular and easily edited to add more servos or thrusters as future designs may need. Sensor information is displayed in its own window on the GUI. Visual representations of the three electronics tubes are present. Humidity and temperature values are shown within these tubes. As the temperature or humidity of the tubes increases or decreases, the tube's representations change color. Red is used for temperature and blue for humidity. Pressure data is converted to depth and displayed through the use of a slider showing the operating depths of the ROV, 0-20ft. The data the GUI receives from the IMU is integrated into the Orientation view on the GUI. In the orientation view, a rectangular 3D box representing the ROV is used to show it's orientation under the water. The raw roll, pitch, and yaw information is used to update this 3D display. The Control, Sensors, and Orientation view combine to create an intuitive interface, allowing a relatively unskilled pilot to have all the information they need to safely and effectively control the ROV.



Front Capsule
Temps: 67.0
Humidity: 5.39%

Middle Capsule
Temps: 67.0 57.0
Humidity: 5.39%

Rear Capsule
Temps: 67.0 67.0
Humidity: 5.39%

Figure 8: Graphical User Interface (GUI) displaying sensor info, orientation, and thruster control sliders.

The control system construction consisted mainly of ordering the correct components, mounting those components to the cold plates, and wiring those components together. The beagle board, IMU and Arduino could be ordered as soon as the controls flow was designed because those components don't depend on the parameters of the ROV system. The voltage regulators and motor drivers were dependent on the requirements of the thrusters so the voltage and amperage of the thrusters needed to be finalized before those components could be ordered. It was determined the thrusters would need no more than 10 amps each and would operate at 12 volts, so motor drivers with a 15 amp max and 12 volt supply were purchased . The custom made voltage regulators were ordered from Vicor. Sensors were then chosen that would integrate easily with the Arduino and a camera servo was also chosen that could be controlled directly from the Arduino.

Once all these components were ordered the layout of the electronics was determined with 3 criteria in mind; the heat generated by the electrical components, the spacing for the connectors and wires, and minimal wiring between electronics tubes. The heat generation was only a concern with the motor drivers but a heat transfer analysis was done and it was determined they could all be placed in the same tube. The spacing for the connections between components was a concern for the beagle board as well as the Arduino, they both were placed far enough away from the end caps to allow there power and data cables to be plugged in. Along with the cable spacing the components position was determined by the flow of data and power to try and minimize tube to tube wiring. The tether enters the back tube, where the first components that the power will interact with are located. The power is stepped down and then passed into the beagle board and the data cable from the tether is plugged directly into the beagle board. Then the data and power are sent into the next tube where the Arduino, IMU and motor drivers are located and the flow then continues to the front tube where the Arduino sends commands to the camera servo.

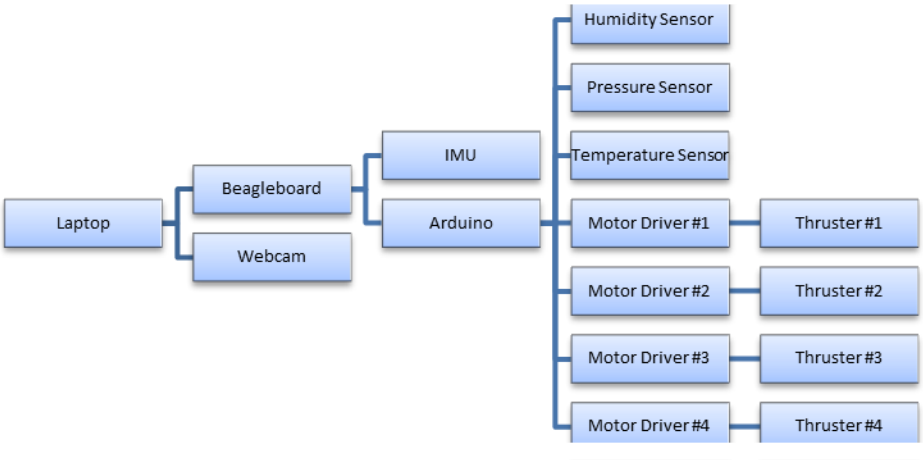


Figure 9: Control system flow chart

Power

The design for the ROV's power system was governed by two main ideas, MATE competition requirements, and meeting the power specifications of the onboard electronics. The MATE competition specifies that the ROV must be powered by a 48V supply on-shore, which will provide up to 40 amps. Additionally, an onshore fuse must be used to prevent any malfunctions onboard the ROV from damaging MATE supplied components or injuring people. The last MATE competition requirement is that any power management or voltage regulation must be carried out onboard the ROV.

To simulate the MATE 48 volt supply, the UNH ROV team uses four 12 volt batteries wired in series to achieve a 48V power supply that can supply up to 40 amps. The fuse box used is equipped with a 30 amp fuse, switch, voltmeter, and ammeter. The fuse is designed to cut power to the ROV if the ROV draws more than 30 amps, that is, more current than the thrusters at full power, and all electronics operating normally. To provide the ROV operator with even more information the voltmeter is added to inform the operator of the current supply voltage, and the ammeter is added to let the operator know how much current is being drawn by the ROV. To actually deliver the electricity to the ROV, braided XXXX Gage wire is used within the tether.

Upon reaching the ROV and passing through the waterproof connectors, the electrical power must now be converted to levels specified by the onboard electronics. The motor drivers require 12 Volts to operate correctly, and the Beagleboard requires 5 volts to operate correctly. 2 Vicor DC to DC voltage converters are used to accomplish these tasks. A 48 to 12 converter is used to power the 4 motor controllers. An additional 12 V to 5 V converter is used to power the Beagleboard as well as the two lights on the front of the ROV. The Arduino microcontroller receives power from the Beagleboard, and in turn powers the on board sensors, IMU, and camera servo motor.

Figure 10: Fuse Box with switch, ammeter, and voltmeter.

Tether

A tether was designed in order to transmit electrical power and data from the surface to the ROV. Electrical power needed to be supplied in the form of 48V from the fuse box to the ROV. Communication data from the camera needed a USB connection and communication from the Beagleboard needed an Ethernet connection. Three wires: Power, USB, and Ethernet, would be run through an expandable sleeve, fastened together with zip ties, and then connected to the ROV. The tether needed to be detachable from the ROV to allow for easy transportation and maintenance of the tether and ROV separately. Underwater buccaneer connectors would be installed in the tether a few feet behind the ROV to be able to connect and disconnect the three wires of the tether to the ROV. In order to reduce drag to the ROV the tether was designed to be neutrally buoyant. Foam pieces would be attached along the tether in order to keep it from sinking to the bottom of the pool.

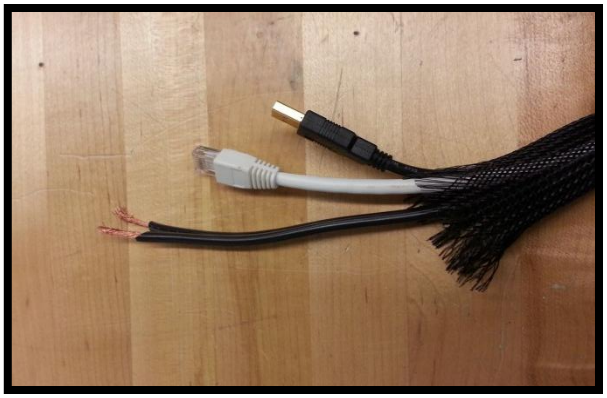


Figure 11: Tether with power, data and video feed cables.

Transmissometer

A transmissometer was designed and constructed in order to complete the mission of “constructing and installing a transmissometer.” A transmissometer is an instrument that measures light attenuation, which can be used to determine the turbidity of water over time. The transmissometer will be installed over a porous disc that rotates about a horizontal axis. The changing porosity of the disc simulates changing water turbidity. The transmissometer needs to be slightly negatively buoyant so that it remains at the bottom of the pool where the ROV deposits it.

For our transmissometer a LED and photodiode configuration was decided on. A photodiode is a semiconductor component that converts photons to current. An OPT101 photodiode was purchased. It is an Integrated Circuit which contains a photodiode and a transimpedance amplifier. The transimpedance amplifier serves the purpose of converting the current through the diode to a proportional output voltage. That output voltage is to be fed into the A/D pin on an Arduino Uno which will read and plot that voltage at 1 Hz frequency. This will allow for real-time signal showing the water turbidity where the transmissometer is located. This photodiode is most sensitive to infrared light wavelengths so 9 infrared LEDs were purchased for a 3X3 array to be soldered on a blank Printed Circuit Board. A separate 12 volt DC lead-acid battery is provided for the competition so the transmissometer will be given its own tether. The tether will consist of power cables to both the LED array and photodiode and a USB for communication with the Arduino. Code was written for the Arduino MCU to graph the real-time output of the photodiode.

ROV Systems Construction

Chassis

The frame of the chassis was constructed out of polycarbonate due to last year's teams advice. The two side panels each have two large cut-outs that decrease the weight of the frame and allow water to flow through them when the ROV is turning. The two sides are held together on the bottom using three small pieces of polycarbonate attached to L-brackets. The top of the side pieces have three semi-circles cut into them to cradle the electronics tubes. The tube end-caps will be screwed onto the outside of the frame to ensure that they do not move.

The electronics tubes are the one of the most vital parts of the ROV because if they are not waterproof, the electronics will get wet and the ROV will be dead in the water. Because last year's design worked so well, the design was adopted and only slightly altered. An acrylic tube is sealed by two aluminum end-caps with O-rings around the seals. The two end-caps are each screwed into an aluminum plate (cold plate) that stretches the length of the electronics tube and is what the electronic components are fixed to. Sealing washers are used where the end-cap has screws passing through it to ensure water tightness. Bulkhead fittings allow the wires to enter and exit the tubes.

The acrylic tubes were ordered first, and the inside ends were chamfered to allow the end-caps to fit tightly inside the tube. During the machining of the tubes, one of them cracked, which forced us to order more acrylic tubes. The inner diameter of the second order varied slightly from the first order, so when we tried to test the tubes for leaks, we found that we could not fit the end-caps into the tubes. The end-caps were machined down slightly, the tube chamfer was increased, and the next size smaller O-rings were ordered. The end-caps were then able to fit into the tubes, but the assembly was not watertight.

Figure 12: Tube, end-cap, o-ring, and bulkhead fitting assembly.

The six aluminum end-caps were manufactured at Brazonics Inc. on a vertical CNC machine. Prior to machining, a design review was held with one of the engineers and some minor changes were made to cut down on cost and improve assembly. There was a larger radius added to the flanges on the end-caps to allow for easier machining. Other design changes included larger clearance holes for the three screws that connect the end-cap to the cold plate and some unnecessary material was removed to cut down on the cost of the stock material to machine the end-caps. Conversion coating the aluminum in irridite was considered to increase corrosion resistance, but determined to be unnecessary due to the corrosion resistance of aluminum, application and duration of use of the ROV.

The three cold plates were milled uniform in the UNH machine shop but was finished at Brazonics Inc. The precision required for the screw hole pattern along with difficulties associated with drilling into the end 18” aluminum plates and required tools for installing helicoils which were only available at Brazonics Inc.

Camera

The camera mount was machined in the UNH machine shop using stock aluminum, a steel rod and a U-bolt to secure the servo motor. A rectangle was milled out of the cold plate to fit the camera and its mount and to allow the camera to pan up and down. The camera was then mounted to the square mounting plate and the mounting plate is attached to the cold plate on one side with the output shaft and on the other side with the stabilization rod. The stabilization rod is threaded into the mounting plate and is slid into the stabilization cube that is fixed to the cold plate. This set up was first configured on the top side of the cold plate which caused the camera to be slightly above the center of the tube. When this set up was placed into the electronics tube it was found that the tube would interfere with the camera as it rotated through its 180 degrees of movement. The camera set up was then flipped onto the bottom of the cold plate so that the camera was centered in the tube and the mount would not interfere with the inside of the tube.

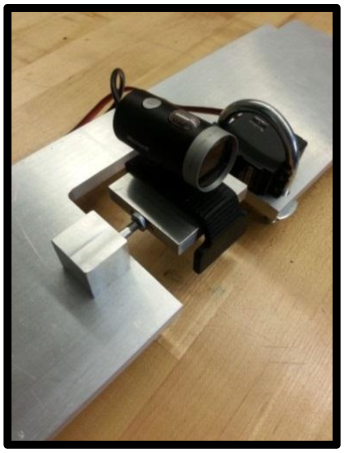


Figure 13: Original camera mount set-up.

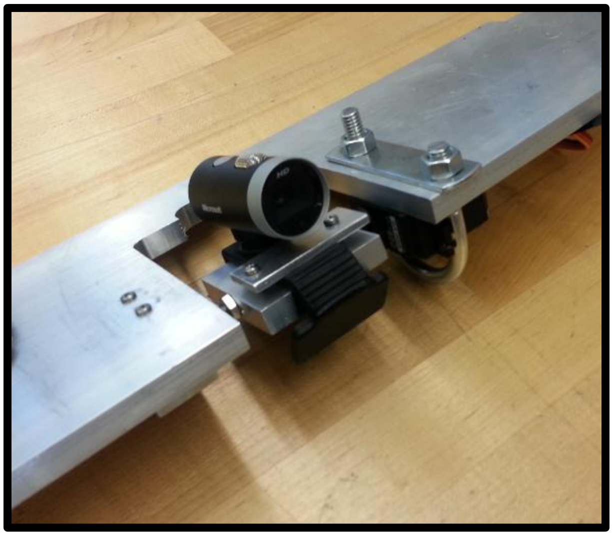


Figure 14: Improved camera mount set-up to eliminate interference.

Thrusters

The decision to attempt to manufacture our own thrusters was made based on multiple factors. Although the 2012 UNH ROV team recommended we purchase commercial thrusters instead of manufacturing our own as they did, the decision was made to manufacture our own thrusters. This was based on the larger manpower of the 2013 ROV team, the prohibitive cost of commercial thrusters, and the availability of dimensioned drawings of the 2012 ROV's thrusters.

The 2012 ROV thrusters can be broken into 2 main categories, drive, and waterproofing. The drive components were consist of a 12 Volt Banebot RS550 brushed DC motor, a 2 bladed 10.5x9 propeller cut down to a diameter of 3", a 4.31:1 gear box, which connected to the propeller. The waterproofing components are more numerous and consist of a cylindrical aluminum housing, a rear end cap to seal off the rear of the housing while allowing electrical wires to pass through, and a front end cap assembly to seal the front of the housing while allowing the output shaft to rotate the propeller.

The 2013 ROV thrusters were designed based on the 2012 thrusters with some modification. The gearbox was removed to decrease its associated resistance torques. To compensate for this, a smaller, slower RS395 motor was chosen. A circular motor fitting was added to properly position the motor within the housing. An output shaft was also added to transfer power to the propeller, and notched to securely attach the output shaft to the propeller.

Most of the thruster components were machined in the University of New Hampshire's machine shop facilities. The aluminum housings were cut to size using hollow aluminum tube stock cut to size with a band saw. A lathe was primarily used to size out the inner diameter of the housing, and match them properly to the outer diameters of the two end caps, using an approximate difference of .002 inches in diameter for a tight seal for the o-rings. The end cap assemblies were also faced off to size with a lathe, and a center hole was drilled through that would allow for the thruster shaft to fit properly through the front end cap. The threading for the back end cap was also done using a lathe. A mill was then used to drill and thread holes for machine screws. Care had to be taken when trying to align the holes 90 degrees from one another around the housing in order for the components to be assembled correctly.

When machining the thruster components a tolerance of .001 inches was used for the center hole inner diameter of the front end, and stuffing box cap as well as the outer diameter of the thruster shaft. This was done to assure a snug fit for the dynamic O-ring seal that protected the motor from water, as well as to maintain a concentric relationship between the thruster shaft and the various fittings around it. These components were machined at a lathe in the university's machine shop.

Once the individual components for the thrusters were fabricated, the assembly process could begin. It was during this process that it became apparent that the tools available in the UNH machine shop were not precise enough to create 4 similar thrusters. The most significant problem encountered was the varying center points of many components. The shaft, motor, motor fitting, housing, and front end cap all needed to be concentric. If any of these center points were misaligned, there was significant interference between the parts, leading to lengthy reworks and large resistance torques on the output shaft. Additionally, holes which were supposed to pass through multiple parts often did not line up, preventing some screws from being used. All of these factors led to the construction of 4 extremely different thrusters with varying levels of efficiency and waterproofing. One of these thrusters was tested to gain an understanding of the impact of different propeller and cowling styles.

Figure 15: Assembly of the 2013 in house manufactured thruster without propeller or cowling.

Figure 16: Propellers and cowlings used in thruster testing.

The purpose of the experiment was to analyze the impact of 3 different propeller styles and 3 different cowling styles on the static thrust produced, voltage necessary, and current drawn by the thrusters.

To test the generated thrust, the thruster was configured with whatever propellers/cowlings were being tested, and attached to a large sea-saw device. The thruster end of the balance was then placed in water, and balanced by adding weights to the opposite side. The thruster was then connected to a power supply. Additional weights were then added to the balance, and the power supplied to the thruster was adjusted until the supplied thrust balanced the additional weight. This process was repeated for 3 propeller styles and 3 cowling styles. The 3 propeller styles were as follows. A 10.5x9 airplane propeller cut to a diameter of 3”, a 3 bladed aquatic propeller, and a 4 bladed aquatic propeller. The three cowling configurations were: no cowling, a flat cowling with rounded edges, and a contoured cowling. The thrust in each direction and power consumed for all configurations is shown below.

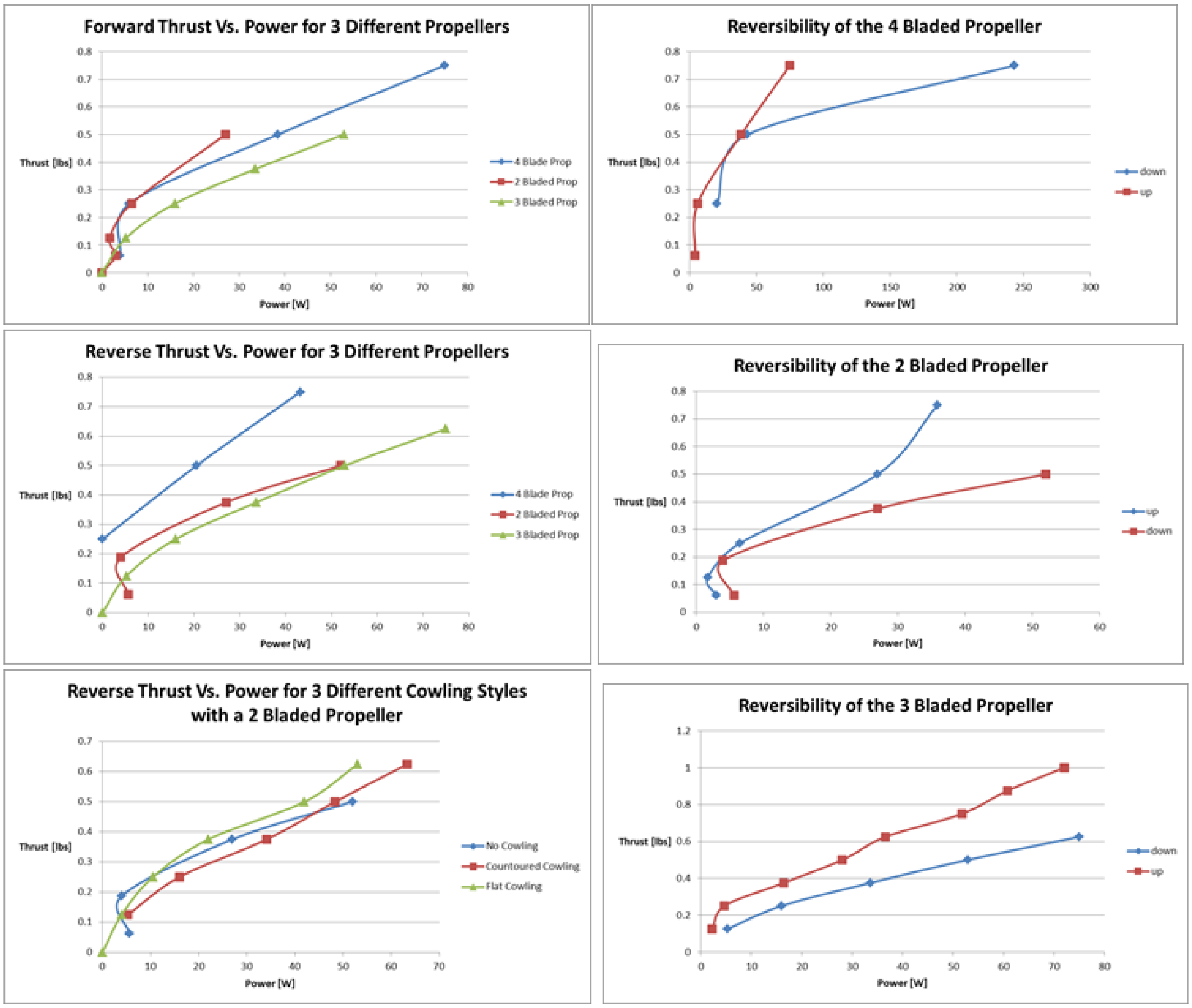


Figure 17: Thruster propeller and cowling data

The data shows that the 2 bladed propeller generated the same amount of forward thrust as the other propellers while drawing the least power. Conversely, the 4 bladed propeller generated the most reverse thrust while consuming the least amount of power. Unexpectedly, the flat cowling produced the same amounts of thrust while consuming the lowest amount of power. Lastly, it can be seen that the 3 bladed propeller had the best reversibility, that is, its behavior in forward and reverse were the most similar. Based on this data it can been seen that a two bladed propeller with a flat cowling works best for its efficient forward thrust, and adequate reversibility.

The design and manufacture of custom thrusters yielded valuable data and an understanding of the necessary components. Unfortunately, the large variability in the thrusters, combined with the lengthy construction times necessitated the purchase of commercial thrusters.

To keep the thruster control and power system from changing, the thrusters chosen were capable of being easy to integrate with the existing propulsion power and control system. This necessitated that the thrusters be DC brushed motors, so they could be controlled with the motor drivers, that the thrusters could run on 12 volts, and would not draw more than 15 amps as stipulated by the motor drivers. These criteria resulted in the purchase of 4 Seabotix BTD150 thrusters.

Figure 18: Seabotix BTD 150 DC brushed thrusters.

Controls

To mount the electrical components to the ROV, mounting holes needed to be drilled into the cold plates inside the tubes. The electrical component layout was marked out on the cold plates with the location of the mounting holes marked to be drilled. The beagle board, Arduino, IMU, motor drivers, all had screw holes in them to make them easily mountable. These dimensions were determined and holes were tapped, drilled, and threaded in the desired locations on the cold plates. These components have some solder and other protrusions on the bottom sides of them so they were raised up on standoffs to prevent damage to the components. This was done by using male to female hex standoffs that would be screwed into the threaded holes in the cold plate and then the component could be mounted and the screws could thread into the top of the standoffs. The 12 volt to 5 volt regulator had a heat sink included with it and the heat sink had mounting holes so that component was screwed directly into the cold plate. The 48 volt to 12 volt regulator had no mounting system so a custom mounting bracket was machined to fix this component to the cold plate. The camera servo was mounted next to the camera with a U-bolt to press and hold it on the cold plate.

Once the control components were mounted the wiring was put in place and fed through the small plastic piping that ran tube to tube. With the wires in place the connections were soldered and finalized. The space in the bulkhead holes was limited and the thruster power cords were too large to fit 4 into the tube at once. The thruster cords had a large amount of insulation and shielding in them that was unnecessary for this application. It was determined that to get the power to the thrusters, wires of the same gage but less insulation would be soldered to the thruster cords and then fed through the bulkhead fitting to make room for them all. This required a sealed PVC connector at the interface between the two wire lengths that needed to be epoxied.

Power

The fuse box housing was made of the same polycarbonate material as the chassis frame, chosen for its strength and nonconductive properties. The frame is 12” by 8” and 3” in height with holes cutout for the components that needed to be exposed. The bottom of the fuse box is see-through for easy viewing of the inner circuitry. The batteries are connected to the fuse box through plugs sticking out of the back which then connect to the fuse.

Tether

The construction of a tether was completed in order to create a fully functional underwater ROV. The design of the tether showed that power, USB, and Ethernet wires would need to connect to the ROV. The wires would need to be wrapped together and ran through a sleeve to create the tether. The wires would also need to be able to connect and disconnect from the ROV through underwater connectors. Finally, foam pieces would need to be attached throughout the tether in order to keep it neutrally buoyant. All the wires were purchased through vendors online and measured roughly 75 feet with the exception of the USB wire which could only be 66 feet due to the limitations of transmitting USB data over long distances. The expandable sleeve, foam pieces, and zip ties for the tether were also purchased from online vendors. The construction began by laying out all three wires down a long hallway and determining where the underwater connectors needed to go behind the ROV. Once measurements were taken the wires were bound together with zip ties. The tether needed to be about 60 feet in order to reach all of the MATE competition tasks in the 33’x33’x20’ pool. The expandable sleeve was cut to sixty feet, and the wires were fed through it. Underwater buccaneer connectors were connected to all three of the wires. Foam pieces were attached throughout the tether in order to keep it neutrally buoyant. Extra wire at the end of the tether near the surface was left to connect to the onshore control station.

Transmissometer

The waterproof container to house the electrical components of the transmissometer was designed with the intention of minimizing the cost. Instead of building our own waterproof boxes and designing watertight seals, two clear waterproof Otter Box Pursuit/40 cases were purchased for $35 dollars each. In order for the power and USB wires to reach the electrical components inside the boxes, a hole was drilled into each box. The wires were inserted through the holes and then permanently sealed with marine epoxy. One of the two boxes leaked during the first waterproof test, but after another layer of epoxy was applied, both boxes were completely watertight.

In order to keep the boxes approximately 6 inches apart with the LED and photodiodes facing each other, an aluminum frame was constructed out of the scrap metal left over from the rest of the chassis construction. The buoyant force of the waterproof boxes was calculated as well as the necessary volume of aluminum to counterbalance the buoyant force. The weight of the boxes and the components inside then make the entire assembly slightly negatively buoyant. The frame consists of two thick vertical side plates that are connected to the waterproof boxes with zip ties, and a thin horizontal plate that connects the two side plates. A U-bracket is fixed to the horizontal plate so that the ROV can carry the transmissometer through the water. The entire assembly can be seen below in Figure 19.

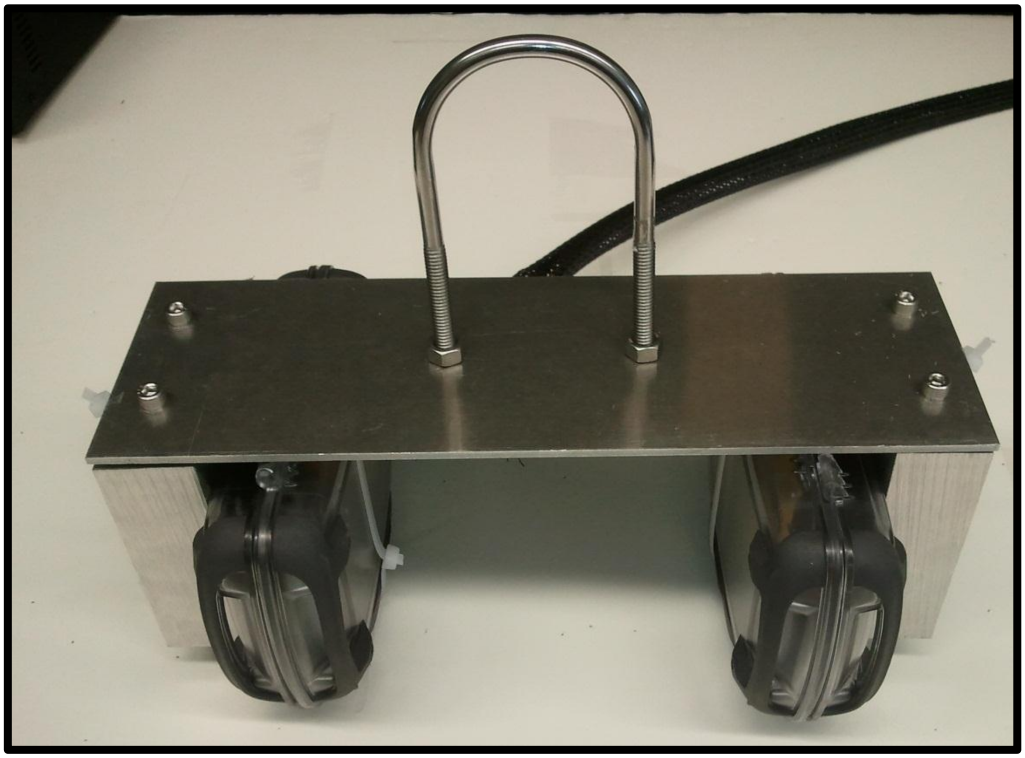


Figure 19: Fully assembled transmissometer.

Discussion

Successes

Throughout the year there have been a number of major successes in the completion of a fully functioning underwater ROV. The first success would have been coming to a conclusion on the design for our ROV. This task was not easy and took a few months to finally come to a finalized design. The second success would be the purchase of thrusters for the ROV. Trying to build our own thrusters was a great learning experience when dealing with underwater components however, purchasing working thrusters was necessary to build a fully functioning underwater ROV. Our third major success came from successful communication from the PS3 controller to control the proper thrusters and camera through the Beagleboard and Arduino hardware components. The fourth major success came from successful waterproofing of the electrical tubes. Without the electrical tubes waterproofed the ROV would fail underwater. Our final and most important success came from the completion of a successful trial run of the ROV underwater with everything working properly. This was of course probably the biggest success for the team throughout the year. A great sense of completion was had once the ROV was performing properly underwater. A number of successes were had through the course of the year while completing a fully functioning underwater ROV.

Possible Improvements

Looking back on this year, some aspects of the design process could have been improved. The thrusters should have been designed to the electrical specifications similar to backup thrusters to be ordered, so that other electrical components didn't need to be ordered to adapt. To avoid numerous modifications to the electronics capsule end caps, each acrylic tube should have been measured so that the caps would be machined for specific tube sizes.

The thrusters that were designed and manufactured by the ROV team used motors that operated at 12V. Once the decision to purchase thrusters was made, an attempt to find thrusters that operated at 12V was unsuccessful. The Seabotix BTD150 thrusters can operate at 12V, but for optimal performance 19V was necessary. In order to supply 19V to the thrusters, an additional power converter is required. Had the original thrusters been designed with 19V motors, then this transition would have been much easier.

The acrylic electronics capsules that were used came from two separate stock orders. Because of this, the loose tolerances on the inner diameter of the tubes caused complications when the machined end caps could not fit into the tubes. The end caps were then sent back to Brazonics to be machined to the inner diameter of a sample piece of tube, however one of the three tubes were of a different size than the other tubes, and so two caps needed to be sent back to fit correctly in the other tube. This delayed assembly by about two weeks. Had all three tubes been accurately measured before machining of the end caps begun, then this issue would have been avoided.

Costs

There was not much money left over from last year's team so this year's team was essentiall left to start from scratch with budgeting. The team created a sponsorship packet to ask for donations from businesses and was able to receive donations from a good amount of the sponsors from last year. This year's team was also aided heavily from UNH with both departments and staff. Thanks to generous donations from family members as well it was possible to build our ROV. An estimated budget for the entire project was laid out at the beginning of the year and the team has done what we could to stick to it. An active spreadsheet was created with all the expenses made throughout the year and was updated with every purchase made by the team. Future UNH ROV teams will have sponsors and complete budgeting information to use for their projects.

Cost Breakdown Chart

System	Expense [USD]
Propulsion System (Purchased Thrusters and additional thruster building material)	$3,500.00
Chassis (polycarbonate plates, aluminum stock, polycarbonate tubes, aluminum plates, O-rings,)	$5,300.00
Chassis continued (Transmissometer materials, bolts, nuts, epoxy, camera)	$300.00
Electronics and Controls (Beagle Board, Arduinos, IMU, and motor drivers)	$1,100.00
Electronics and Controls continued (Switches, LEDs, pressure and temperature sensors)	$200.00
Tether Materials (Braided Sleeve, Wires, Cables, Camera)	$400.00
Mission Task Mock Up Course Materials (PVC, Hardware, etc)	$300.00
Miscellaneous (Waterproofing, Mission Task Equipment, Fundraising Supplies, Team Shirts, Presentation Poster, Banquet, Computers, MATE Competition Entry Fee)	$2,000.00
Estimated Total Expenses as of 4/27/12	**$13,100**

Donations

Donations	Amount
Brazonics (Chassis Material and Labor)	5,300.00
OE Department	2,000.00
CEPS Dean's Office	3,000.00
ME Department	1,050.00
ECE Department (Controls Material)	1,100.00
Professor Thein	1,000.00
Portsmouth Naval Shipyard	500.00
Hitchiner Manufacturing	100.00
Todd Gross	200.00
Jay S. Smith	500.00
Raymond Dow	100.00
Ray and Ann Dow	100.00
Kelly Dupuis	50.00
Tom and Alex	80.00
Total	**13,980**

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- Professor Thein
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- Professor Fussell
- Professor Miller
- Bob Champlin

References

1) "Brushed vs Brushless Motors." - *Think RC*. N.p., n.d. Web. 28 Apr. 2013.

2) "MATE - Marine Advanced Technology Education :: EXPLORER." *MATE - Marine Advanced Technology Education :: EXPLORER*. N.p., n.d. Web. 28 Apr. 2013.

3) "Maximizing Propulsion Efficiency." *Maximising Propulsion Effeciency*. N.p., n.d. Web. 28 Apr. 2013.

4) "Parker - Engineering Your Success." *Parker - Engineering Your Success*. N.p., n.d. Web. 28 Apr. 2013.

5) "Standard Tap Drill / Clearance Holes Table - Engineer's Handbook -." *Standard Tap Drill / Clearance Holes Table - Engineer's Handbook* -. N.p., n.d. Web. 28 Apr. 2013.

6) "USB Cable Length Limitations And How To Break Them." *USB Cable Length Limitations And How To Break Them*. N.p., n.d. Web. 28 Apr. 2013.