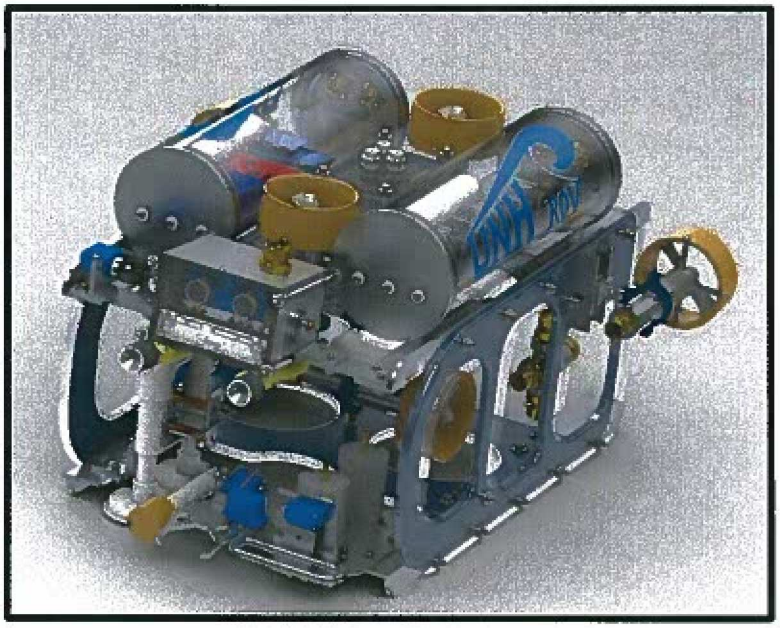
2012 University of New Hampshire Remotely Operated Vehicle

TECH 797 Final Report

April 27, 2012



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1.0 INTRODUCTION

1.1 Abstract

An *Underwater* Remotely Operate Vehicle was designed, built, and tested by 2012's UNH ROV team. UNH ROV is a competition and research based interdisciplinary senior design project supported and funded by the University of New Hampshire and the NOAA Sea Grant. This year's ROV team has been built an ROV that will serve a dual purpose as a research and competition based vehicle. The competition is held by the Marine Advanced Technology Education center, Orlando, Florida on June 21, 2012. The vehicle has also been designed to support research in advanced 6 Degree of Freedom ROV Control Systems.

1.2 Background

Underwater Remotely Operated Vehicles (ROVs) play a significant role in ocean exploration and carrying out missions for which human-occupied vessels are not feasible due to physical, technical, and monetary limitations. ROVs are able to perform more productive missions and operate at much greater depths than human-occupied marine vehicles. ROVs are characterized by their tether, which links the ROV to a ship. The ROV's tether provides electricity, communication, and control. Unlike the operators of manned underwater marine vehicles, ROV operators reside safely in ship at the other end of the tether. These highly trained ROV pilots rely on sophisticated camera systems, robotic fixtures, and highly maneuverable electric propulsion systems to control the ROV.

The University Of New Hampshire (UNH) is well known for its involvement in marine science and engineering. Because UNH is a Sea Grant school, it is able to facilitate marine undergraduate senior design projects. The Marine Advanced Technology Education (MATE) center is an organization whose mission is to promote education in marine technology and who hosts a yearly international intercollegiate ROV competition.

In 2009 and 2010, UNH had two MATE competition based ROV teams under the name SEACATS, but the organization ended in 2011. This year's ROV team has a new name and a revised mission statement. The team has been renamed *UNH ROV* and its mission is to design, fabricate, and test a fully functional ROV that will compete in the 2012 MATE ROV competition and serve as a platform for the research and development of ROV technologies. In addition, designs will emphasize the importance of modularity and expandability.

1.2 Goals

This year's team has set several goals based on maximizing the ROV's ability to serve a dual function as competition and research based platform.

- To design, analyze, fabricate, and test of a fully functional ROV,
- To compete in the MATE international ROV competition,
- To build a modular platform that can be used for research,

The ROV team was divided into three subgroups: Controls, Propulsion, and Chassis. Sub-groups focused on designing major ROV components such as the control system, thrusters, camera systems, and waterproof housings. However, efforts were coordinated to produce an effectively *integrated* design. The importance of *modularity, expandability, and functionality* in ROV design was emphasized by all sub-groups.

Team members fabricated almost every component on the ROV, with the exception of parts that could not fabricated in the UNH machine shop due the limitations of available machines. This decision was based on design, time, and monetary constraints. If the ROV were to be fabricated by hired machinist, the costs of fabrication would surpass the available funding.

Testing consisted of bench trials of individual components, then individual systems, water testing to ensure watertight integrity, and finally tank testing of the completed ROV. Extra caution was taken during testing due to the risks associated with submerging electrical systems in water.

2.0 MATE COMPETITION

2.1 2012 Competition

The UNH ROV team with be competing in the MATE Center's 11th annual International Rover Competition in June 2012. This competition brings together students from elementary schools, middle schools, community colleges, universities, and community organizations from all over the world to compete in specified mission tasks designed around a certain theme for the year. The mission tasks and themes are based on real situations for ROVs in a natural environment. This year's theme is based around exploring and documenting shipwrecks, with a title of *Diving into History: The Role of ROVs in Exploring WWII Shipwrecks*. Depending on the education level and sophistication of the ROV, there are different mission tasks to be completed, dividing the competition into three classes; scout, ranger, and explorer. UNH ROV will be competing in the explorer class, which is comprised of university teams. The competition is comprised of four components; underwater mission, technical report, engineering presentation, and poster display. The underwater mission is comprised of two main mission tasks and is described in Section 2.2. This year's competition is being held in Orlando, Florida.

2.2 ROV Tasks

The underwater mission to be completed by the ROV is divided into two main tasks, surveying the *SS Gardner* shipwreck site and removing fuel oil from the shipwreck. The *SS Gardner* was hit by a German U-Boat and sunk off the coast of Cape Canaveral on December 25, 1942, close to a year after Pearl Harbor during WWII. All of the crew members onboard were able to escape on lifeboats and were taken to safety in Fort Peirce, Florida. There were no reports of major oil spillage when the vessel was hit and there are still no reports of oil sightings in the area, which means there is still oil onboard the submerged ship. Water corrosion has deteriorated the hull of the ship and major concerns about a break in the hull have come to the attention of many. The MATE competition has designed a mock *SS Gardner* shipwreck for the ROVs to explore and fix. The entire mock shipwreck is made almost completely of PVC pipe and includes a ship, grid, fuel tank, coral, and mast, shown in Figure 1, Figure 2, Figure 3, Figure 4, and Figure 5. The MATE Center will provide the shipwreck components at the International Competition in Florida, but to practice at UNH, the team has fabricated a set of the materials also. The dimensions of the setup pieces are shown in Table 1. The MATE ROVER website detailed all instructions on how to build the mock shipwreck.

Table 1: Materials and Dimensions of Mock Shipwreck

Item	Material(s)	Length	Width	Height
Shipwreck	PVC pipes, 90° elbows, T joints, PVC glue	10"	34'	32'
Grid	PVC pipes, 90° elbows, T joints, PVC glue	5'	---	98"
Coral	PVC end cap, pipe cleaners, glue, and Velcro	---	---	5"
Mast	PVC pipe, cross joint, U-Bolt, glue, string	18"	---	3'
Fuel Tank	PVC pipe, caulking, clear plastic	---	6"	14"

Figure 1: PVC *SS Gardner* shipwreck

Figure 2: PVC grid

Figure 3: Mock coral made of PVC end cap and pipe cleaners

Figure 4: PVC mast with U-bolt

Figure 5: Mock fuel tank made of PVC and clear plastic

Task 1 consists of measuring the overall length of the wreck and determining the orientation of the wreck on the seafloor. The team must also determine if material on the seafloor near the site is metal, and therefore from the ship, or non-metal, and therefore natural parts of the environment. This material debris will be in different squares of the PVC grid on the floor. Once the material make-up of the debris is determined, a map of the entire shipwreck, including debris, must be made. The ROV must also be able to scan the ship with sonar at three target locations to collect more information about the body of the shipwreck. The responsibilities of the ROV in Task 1 can be completed in any order and each exercise is worth a different amount of points.

Once Task 1 is complete, the team can start on Task 2. The main missions of this task are to remove debris from the wreck and then extract fuel from the ship. A lift bag must be transported to the wreck location, properly attached to the very heavy mast of the ship, and inflated using an air-line to safely move the mast to a designated location without it dragging along the bottom of the pool. Next, pieces of endangered coral must be removed from the ship's hull and transplanted to a safe location within the grid. Once the wreck area is cleared, two simulated sensors will be used to determine if fuel still remains on the shipwreck. The first sensor is an ultrasonic thickness gauge while the second is a neutron backscatter device. The thickness gauge will be used to measure the thickness of the hull material then the neutron backscatter device will be calibrated against this thickness. The calibrated neutron backscatter device will be used to determine if fuel remains on the ship. The simulated sensors must remain in contact with the hull or calibration tank for a consecutive five seconds. Because these sensors are not true sensors, it is just assumed that there is oil on the shipwreck and it must be removed. The ROV must simulate drilling holes into the tank by penetrating a thick layer of petroleum jelly, remove the fuel, and replace it with surrounding seawater without any fuel leaking into the ambient water. The ambient seawater must be pumped into the tank to the hull does not collapse due to pressure. Once the fuel is extracted and the seawater is pumped in to completely fill the tank, the drill holes must be resealed using a cap or patch. The different jobs in Task 2 must be completed in order and are worth different amounts of points. There is a fifteen minute time limit to complete all of the jobs in Task 1 and Task 2.

2.3 Rules and Regulations

2.3.1 Qualifying

In order to qualify for the International MATE Competition, each team must participate in a regional contest. At regional competition, the team must demonstrate that their ROV is able to move in the water. The International MATE Competition will consist of the Mission section and Engineering & Communication section.

2.3.2 Time

Each team receives two attempts to complete the underwater mission and the higher of the two scores will be counted. Teams receive five minutes to set up their ROV and control system, fifteen minutes to accomplish the mission tasks, and an additional five minutes to break down their set up. Once the missions are complete, the clock will stop when the ROV has surfaced on its own power and touched the side of the pool allowing for one team member to touch the ROV. There is a time bonus for completing all mission tasks before the fifteen minute limit. The five minute break down time begins as soon as the fifteen minute competition time is over, regardless of whether every task was completed.

2.3.3 Safety

To ensure safe operation, the following requirements must be met:

a. Documentation of all electrical systems or power distribution for the ROV must be provided to the judges,

b. Anything attached to the ROV must be secured to not fall off during competition,

c. All hazardous or dangerous substances or components on the ROV must be identified and protected,

d. No sharp edges or elements that can cause injury to personnel or damage to the pool surface are allowed on ROV,

e. There must be a signal attachment point to the power source with a proper connector,

f. All power conversion must take place on ROV underwater.

3.0 DESIGN CRITERIA

3.1 General Requirements

Design criteria were established based on functionality. Some competition based teams design their vehicles tailored to the competition, but because of the technical challenges associated with the design of an ROV, UNH ROV has decided to set design criteria based on creating a modular, expandable, and modifiable ROV platform, or vehicle class. Following year's teams will not have to waste time redesigning components that were designed this year.

Building an operational ROV is not easy. For the vehicle to operate in its most basic function, it must be 100% waterproof. When an ROV is deployed underwater it cannot be accessed easily. This poses a great problem if electrical or mechanical systems are malfunctioning, which could damage critical systems like the power-converters, motor controllers, or computer networks. *Simply put*, the ROV cannot even be tested unless all systems are functioning properly. Failure of the waterproofing system, which includes gaskets, fittings, O-rings, and sealant, could destroy the ROV.

3.2 MATE Specified Capabilities

Along with performing basic maneuvering tasks around the shipwreck and providing a visual of the entire underwater shipwreck area, the ROV must execute other tasks specific to the MATE International Competition. The ROV must be able to utilize a manipulator arm and inflatable lift bag to pick up items from the shipwreck and move them to safe locations on the sea floor. After the area is clear of debris, the ROV must be able to implement a pump system to extract fuel from the ship's fuel tank and replace it with surrounding ambient water. The fuel tank must also be capped and sealed after the fuel is extracted. With these requirements set forth by MATE for the competition, the team has implemented systems to complete the mission.

4.0 MODULARITY

4.1 Modular Design Approach

Modularity has been a theme from the beginning of the design process. UNH ROV has broken its modular design approach into several topics:

1. Design Life
2. Durability and Integrity of Designs
3. Reverse Compatibility
4. Independently Functioning Systems
5. Effective Documentation

Designing, fabricating, and testing components is an iterative process and components should be designed and built with a specified design life. This will insure that following years teams do not waste time redesigning component designs that can be reused and modified.

Because the ROV will be used as a research vehicle after the MATE competition, it will need to endure multiple deployments without malfunctioning. This will require proper maintenance and constant checking of the waterproofing systems.

Reverse compatibility on the ROV refers to establishing standard interfaces between systems, whether it is mechanical or electrical. For mechanical systems, hardware must replaceable and fairly consistent, while for electrical systems, connections should be permanent and wiring should support the addition of new devices.

While the ROV operator has control over its functions, the ROV's computer is actually in control over the vehicle's electromechanical operations. This insures that a loss of communication will not cause multiple system failures. The ROV has two microcontrollers, one for collecting sensor data and the other for controlling thrusters, servos, and other electromechanical systems. If one of these microcontrollers were to fail, the other can take over its crucial functions.

Future UNH ROV teams cannot inherit designs that are not well documented, which should include engineering drawings, CAD models, reports, code commenting, and a collection of all available data sheets for components used on the ROV. Some of this year's team members will be available for technical or design related questions or advice. After graduation and before the mate competition, a manual for the ROV will be written. This document will also include information pertaining to the maintenance and care of the ROV.

4.2 Applications on the ROV

Modularity from mechanical standpoint is implemented on the chassis and external structures because they can be easily removed, repaired, or modified. The ROV has been designed so that it can be disassembled and reassembled using only a couple of hand tools.

The ROV's core electronics system consists of an On Board Computer (OBC), two Microcontrollers, two Inertial Measurement Units (IUMs), and three digitally controlled Motor Drivers. All of these devices are mated via Serial and Ethernet connections. All boards can be reprogrammed remotely and because components are connected via an Ethernet switch, it is in essence *digitally wired.* A diagram of this electronics system configuration can be seen in Figure 15 and a diagram of device communications can be seen in figuration can be seen in Figure 16. These diagrams will be further described and explained in sections 6.4 and 6.5.

There are several advantages of having the ROV's electronics system based on Ethernet protocol network communications. All devices connected to the network can communicate freely we each other, new devices can be added without modification to the core electrical system, and in the event of system failures other devices can take over critical system functions like the collection of IMU data or the control of the motor speed controllers.

The theme of modularity is present on the software level. The OBC actively controls the ROV's electro-mechanical systems. One of its primary responsibilities is vehicle stability control, which is achieved with the use of an IMU that consists of an Accelerometer, Gyroscope, and Magnetometer. This system will be described with more detail in section 6.4.

Rather than directly control the ROV's thrusters, the computer used by surface operator sends commands to the OBC, which interprets them and decides how to best implement the desired commands or special orientation. Through the tether's Ethernet cable, the surface computer is plugged into the Ethernet switch that is connected to all other Ethernet capable components in the ROV's electronics system. Because the surface computer is plugged into the ROV's network, it can get permission to control motors, sensor data, and secondary sensor data. This configuration opens up a world of possibilities that are only limited by software, which can be rewritten and reprogrammed remotely.

5.0 SYSTEM DESIGN

5.1 Overall Configuration

The ROV can be broken down into several sub-systems: Chassis, Propulsion, Electronics, Controls, and Cameras. The electrical and mechanical interaction between these systems is necessary for the ROV to function properly. Team structure was built around these sub-systems with team leaders acting as technical liaisons between subgroups.

It is important to briefly review some more technical details about the ROV systems before ROV Systems are discussed. The chassis sub-system includes the frame, two cylindrical capsules, center sensor box, camera box, and thruster mounting systems. The propulsion sub-system consists of the thrusters, propeller, cowling, supporting electrical components, and ROV Direct Current (DC) power conversion. Electronics sub-system consists of one computer, two microcontrollers, three DC motor speed controllers, several ROV sensors, and network devices (Ethernet switch).

5.2 System Interaction

The interaction between sub-systems on the ROV is at the core of its modular platform design. The two main electronics pods can be removed with a quick release strap. The pods also have O-ring sealed end-caps that can be removed without disassembling the ROV. All structural components are assembled with hardware so the ROV can be disassembled without damaging any components. The tether is mated to the ROV with detachable bulkhead connectors, which allows the ROV to be disconnected for transport or to modify/replace the tether.

Electrical systems were built to support the addition of up to 16 thrusters. With two microcontrollers that have many unused digital, analog (with 10 bit resolution), and Pulse Width Modulation (PWM) analog output pins, new sensors can be added at any time without significant modification to the system architecture. Devices operate independently and communicate with industry standard communication protocols, which will allow other devices to step in and take over in the event of system failures.

5.3 User Driven Functionality

By definition, ROV's are remotely piloted vehicles. Typical ROV operators have control over the vehicles depth, direction of motion, and manipulator arm movement. This can make operating an ROV difficult and often requires multiple operators. ROVs typically have a pilot and a secondary operator who operates the manipulator arm and other mobile external fixtures.

UNH ROV has decided that the development of quasi-autonomous guidance and stability control systems could actually increase an ROV pilot's ability to control the ROV. For example, if an ROV pilot needed to operate a manipulator arm, stability systems could actively stabilize the vehicle and decrease the effects of drift due to underwater currents while he or she controls the manipulator. If this system is implemented properly, one operator might have the ability to control all ROV functions.

This year's ROV has 6 thrusters, which can be difficult to control with only eight fingers and two thumbs. To perform maneuvers that change the ROV's position, certain thrusters need to be fired in specific sequences and for certain amounts of time. With the implementation of quasi-autonomous guidance and stability control systems, UNH ROV envisions a trajectory based user control system where the user controls are a point where you want to go rather than manual control of an the ROV's propulsion system, which can often be difficult to conceptualize. Autonomous ROV control systems will increase the pilot's overall control of the vehicle. With further development this system could be used to control fleets of ROVs, as long as they are connected to the Ethernet network (possibly with additional tethers).

6.0 ROV SYSTEMS

6.1 Chassis

The main chassis, shown in Figure 6, was designed with the idea of it being modular, minimal, and open. Modularity would allow for the adaptation of devises required for mission tasks and any additional parts needed to be added for proper function of the ROV. In order to be modular, the chassis would have to incorporate rigid, easy to machine, and transferable pieces. It was originally conceived that the bulk of the ROV would consist of aluminum, but ultimately the material was chosen to be plate polycarbonate due to its weight reduction and lower cost. The targeted mass of the frame was 27.2kg for lifting safety and maneuverability purposes. A simple and open design was planned to reduce its drag and mass, both of which would decrease the vehicle's maneuverability. By having an open design, fluid flow would be less obstructed, thus reducing the power required by the motors. The open design would also help during wiring and reduce the risk of cross wiring. The size of the frame was based on the dimensions of the electronics capsules and a speculation for the different mission task components.

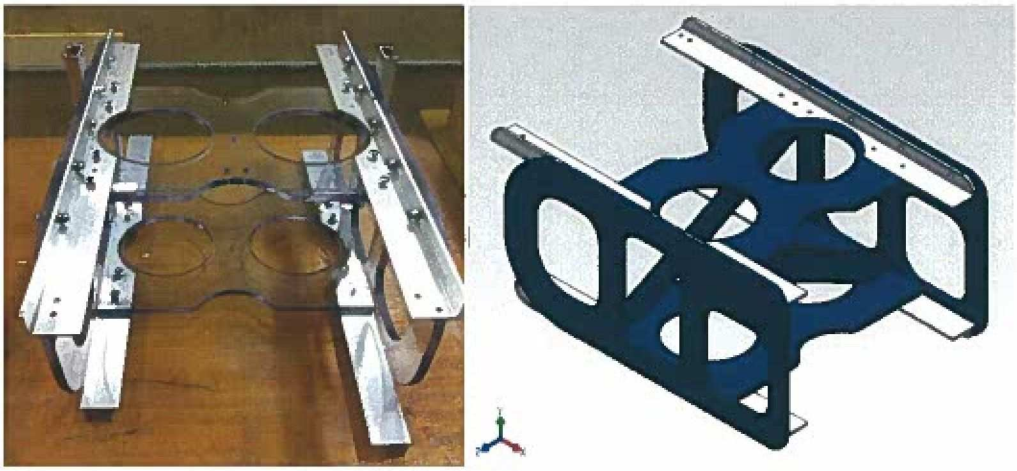

Figure 6: Fabricated frame and SolidWorks model of frame

6.2 Capsules and External Structures

With many electrical components onboard the vehicle, a main design aspect in the planning of the ROV was waterproofing. To allow for efficient use of space on the ROV and proper functioning of the electronics, two main electronics capsules, one center box, and one camera box were designed and are shown in Figure 7.

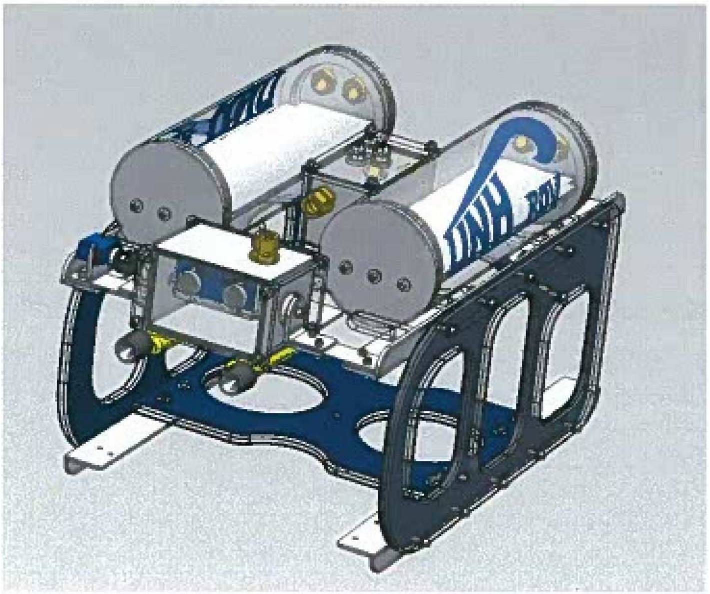

Figure 7: ROV Assembly with Capsules and Boxes. The polycarbonate and aluminum frame with electronics capsules on top with center box in between and camera box in front.

The main electronics capsules house the power converters, motor controllers, onboard computer, microcontroller, and the Ethernet switch. The center box contains another microcontroller and the Inertial Measurement Unit, which has an accelerometer, gyroscope, and magnetometer. This box is located as close to the center of gravity for the ROV to provide very accurate position measurements for the feedback controls. The camera box is located at the front of the ROV and contains three cameras. Two forward facing cameras allow for high definition 3-dimensional vision for the operator while one rear facing camera provides a view to the back of the ROV. Each of these structures was waterproofed with room temperature vulcanizing (RTV) silicone sealant or thick O-Rings.

6.2.1 Electronics Capsule 1 & 2

Two electronics capsules were designed to house almost all electronics onboard the ROV. The dimensions of these capsules dictated the main dimensions of the ROV frame and were based on the sizes of the electronic components inside. The selected tubing was a clear 3.175mm thick LEXAN cylinder to allow for easy viewing into the tubes. The aluminum end caps were fitted with bulkhead fittings, which allow for the electrical wires to pass through the sealed wall of the end cap without any water leakage. The end caps were fitted with large, 6.37mm thick, 146mm diameter O-Rings to completely protect against water seepage. The thick O-Ring was used to compensate for any variance in the inner or outer diameter of the LEXAN tubes. The end cap with O-Ring is shown in Figure 8. Both end caps were connected by a 9.5mm thick aluminum plate that serves as the electronics tray. The plate and ends caps also serve as a heat transfer device, allowing for any heat produced by the electronics to be dissipate to the ambient water outside the tubes.

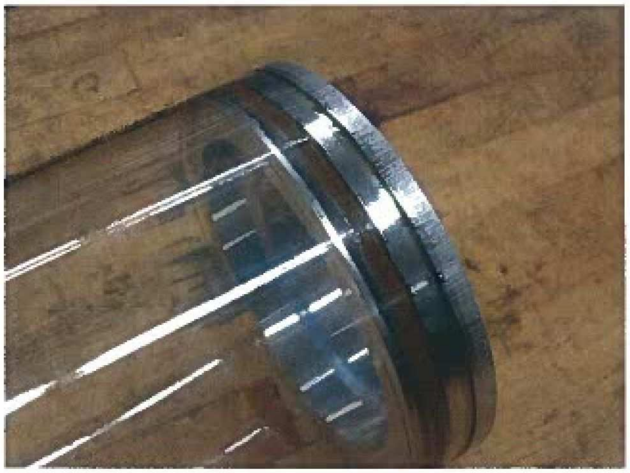

Figure 8: Electronics Capsule. An end cap for the electronics capsule is shown with O-Ring and polycarbonate cylinder.

The design for the hardware onboard the ROV included two different electronics capsules to allow for a separation between the electronics that produce a lot of heat and the more delicate pieces of hardware. Electronics Capsule 1, shown in Figure 9, includes two Vicor power converters and three Sabertooth 2x25 motor controllers. This tube contains the electronic components that produce more heat. The heat transfer through the aluminum plate was analyzed using a finite element analysis approach and showed that the temperatures reached in the tube were well within the tolerances of the electronics. Electronics Capsule 2 contains one Beagleboard single onboard computer, one Arduino Mega Microcontroller, an Ethernet switch, and a low power Vicor power converter.

These pieces of equipment are much more delicate than and do not produce as much heat as the power converters and motor controllers.

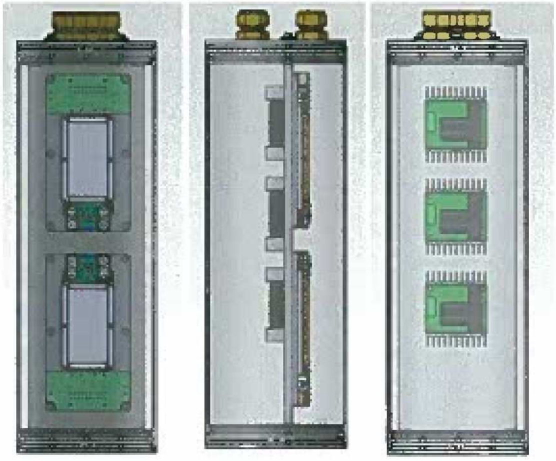

Figure 9: Bottom, Side, and Top Views of Electronics Capsule 1 in SolidWorks

6.2.2 Center Box

The center box was designed to holds the two Inertial Measurement Units (IMU) and one Arduino Mega Microcontroller for the ROV. This device has an accelerometer, gyroscope, and magnetometer and is used to send the control system feedback data about the position of the vehicle. Because of the sensitive data being collected with the IMU, they had to be placed as close to the center of gravity of the ROV as possible. The center box, shown in Figure 10, is made out of aluminum box tubing with two clear polycarbonate lids. The polycarbonate lids were sealed to the aluminum box with room temperature vulcanizing (RTV) silicone sealant to fully protect against leaking. Bulkhead fittings were used to allow wires and USB connections into the box.

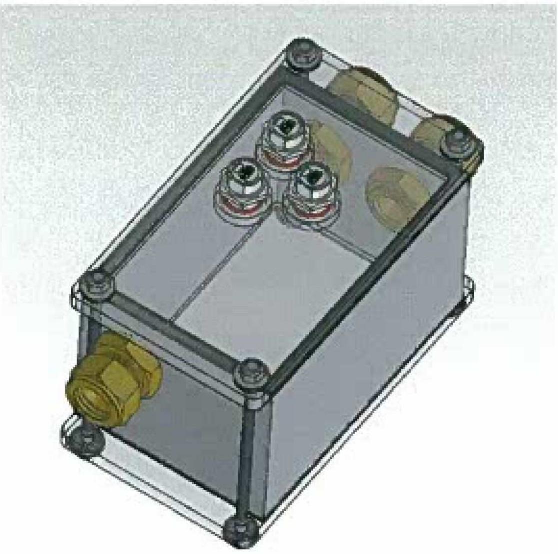

Figure 10: Center Box. The aluminum box and polycarbonate lids are shown with bulkhead fittings on the sides and top.

6.2.3 Camera Box

A single housing, with 180 degrees of vertical rotation, was designed to hold three cameras, as shown in Figure 11. This camera housing was positioned at the very front of the ROV. With two forward facing cameras and one backward facing camera, this box allows for a full 360 degree view around the ROV. The housing was made from boxed aluminum with two clear polycarbonate windows for viewing. RTV sealant was used between the lids and the aluminum box for waterproofing. A dampening coupling was put between the servomotor, which is used to rotate the box, and the housing so that sudden rotational movements from the servomotor would be slightly damped. This would create a more pleasing viewing experience without jerking motions for the operator of the ROV. All three cameras in the housing are positioned in parallel. The two primary cameras facing forward provide uncompressed digital high definition 3-dimensional imaging to the operator. They are optimally spaced 55 mm apart, which is the average spacing between adult eyes. The rear camera will provide the operator with a normal 2-dimensional view of the rear of the ROV.

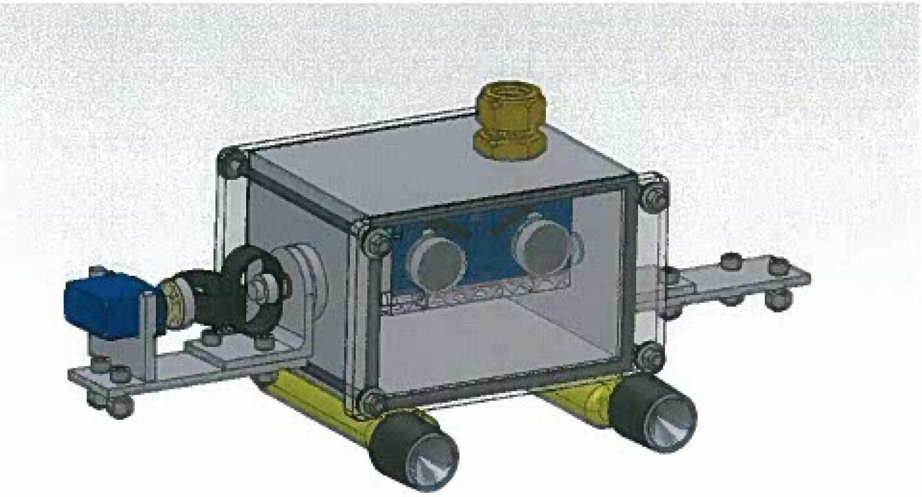

Figure 11: Front view of SolidWorks model of camera housing. Servo motor and damping coupling is shown on the left and two flashlights are connected to the bottom of the camera box. The two cameras facing forward are shown also.

6.3 Thrusters

The ROV's propulsion system utilizes six thrusters. The thrusters were designed to utilize space effectively which resulted in a small overall package similar in size to the Seabotix thrusters which are commonly used to propel ROVs of a similar size to the UNH ROV, shown in Figure 12.

Figure 12: Complete thruster partially assembled

The motor used in each thruster is a RS550 DC brushed motor with a long back shaft which could be used to attach an encoder later on if desired. The propellers used were originally designed to be placed on a large and slow park flyer remote control airplane. To use them on our thrusters, they had to be cut down to the desired outer diameter and the rotating speed had to be kept below 2000 RPM to reduce cavitations, a phenomenon which robs propellers of thrust. To achieve these speeds, a planetary gearbox with a 4.3:1 gear ratio was bolted to the front of the motors. The thruster housings were waterproofed using O-rings on both ends and the rotating shaft was sealed using a lip seal. The propeller was chosen by testing several different propellers and choosing one based its thrust and reversibility characteristics. The propeller cowlings themselves can increase thrust up to 50 percent if designed properly. The goal in creating the propeller cowlings was to create an airfoil shape; this actually helps create more thrust in the form of lift, similar to the lift from an aircraft wing. The design chosen was that of a MARIN 37 Kort nozzle profile, as shown in Figure 13. This profile was chosen for its good thrust and reversibility properties. The outer diameter for the propeller was chosen such that it would be about one to two millimeters away from the cowling to reduce tip losses while also preventing collisions between the two.

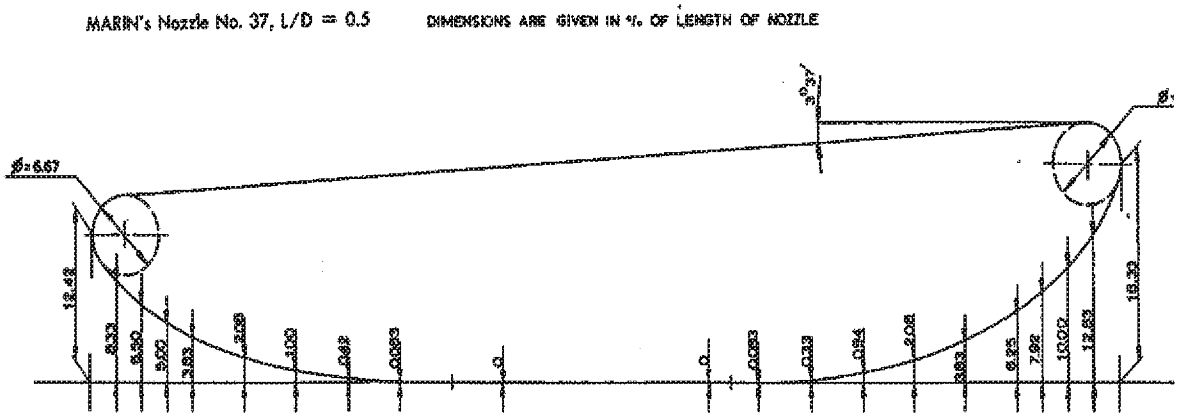

Figure 13: Profile view of Kort nozzle used in thrusters

6.4 Controls

The ROV's feedback control system is based on a 6 degree of freedom dynamic model. Feedback is provided from the Inertial Measurement Unit (IMU), which includes an accelerometer, gyroscope, and magnetometer. Primary inertial measurements are taken by the IMU's accelerometer and gyroscope, which measure linear acceleration and angular velocity. The magnetic heading measured by the magnetometer is used to correct drift in the gyroscope [4]. Linear displacement is represented by the variables x, y, and z (surge, sway, heave) and angular displacement is represented by the variables φ, θ, and ω (roll, pitch, yaw). The angular displacement values are converted into Euler angles, which are required for kinematic and dynamic calculations.

The ROV's control system is based on trajectory flight path corrections. As the user decides where he or she wants to direct the ROV, the desired trajectory is updated and set for a small period of time. If the ROV were to perform all desired corrections within the time period, the control system will stop and wait for the next trajectory update. If the user updates the trajectory, the control system restarts with the new reference and continues to make corrections. Because this control system self corrects based on deviations from the desired flight path, the system is fundamentally autonomous. This can also be thought of as a drive by wire system because the pilot does not directly control forces and moments used to correct the ROV's inertial position. If all reference variables are set to zero, the ROV will perform self-stabilization maneuvers until the original inertial position is restored. This feature will allow the user to set the ROV to hold its inertial position, while performing required position corrections.

The current controller design is based on 6 Proportional-Integral-Derivative (PID) controllers, one for each Degree of Freedom (DOF). A PID control algorithm is commonly used for a wide variety of systems [1]. All angles in the 6 DOF are converted Euler angles for calculations [2]. Six degree of freedom based on Euler angles and he provides equations for transformation matrices used to perform mathematical operations such as rotations and integration of angular velocities to determine position [3].

A visual representation of the effect Euler angular rotations have on each other can be clearer than a written description if a proper derivation is not available. The picture of a visual representation of Euler angles can be seen in Figure 14. In the picture, the *N* ring represents the rotational inertial reference. The ROV would reside inside the red ring.

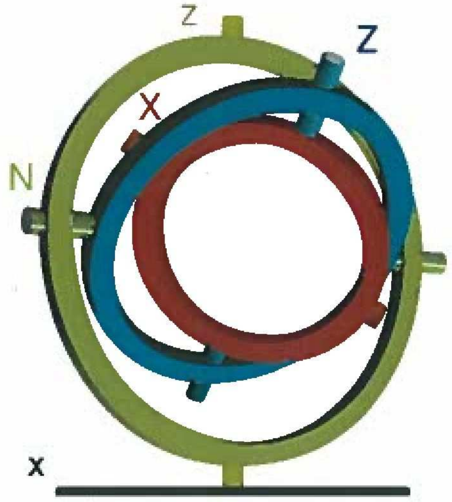

Figure 14: Visual Representation of Euler Angles

6.5 Electronics

The ROV's electronic control system consists of one Single Board Computer (SBC), two Arduino Microcontrollers, three digital DC motor speed controllers, and two Inertial Measurement Units (IMUs), and one commercial grade Ethernet switch. All devices are networked together via the switch. A diagram of the configuration of this system can be seen in Figure 15. The ROV's tether has an Ethernet wire that connects to the Ethernet switch inside the electronics capsules. Because the computer running the user interface plugs into the tether, it is plugged into the ROV's Ethernet switch.

The architecture of this electronics configuration has been based around the need for quick and efficient communications between devices. A flow chart of the communications between devices can be seen in Figure 12. As is depicted in the chart, the heart of this system is the commercial grade Ethernet switch. All computing devices are connected and can have data connections of up to 1 Giga-bit/sec. And far as the ROV is concerned, the surface user interface computer is inside the ROV because it is plugged into its network, which is illustrated by light blue arrows that connected all the block representations of these devices into the Ethernet switch block.

In the ROV electronics network communications diagram Figure 16 in the solid lies represent communications connections, Ethernet, Serial/USB, or Analog Voltage, that are actively used while the ROV is operating. Lines with arrows on each end represent two-way communication and lines with a single arrow represent one-way communication between devices. Dashed lines of the same color represent connections that are either auxiliary or used to reprogram firmware on the devices. Please see the key in this diagram for a visual definition of these arrows.

There are several advantages to this configuration. Because all devices are connected to an Ethernet switch, they can freely communicate with each other. If one device fails or becomes unresponsive, another device can be commanded to take over. The ROV has complete control of itself because the control system runs on its Linux based On Board Computer (OBC). This means that the computer running the user interface above the waterline sends commands that are interpreted by the ROV's computer and in the event of communications loss; the ROV will still function normally and can be programmed to surface, wait, or enter an autonomous mode.

With the write software and controls algorithms, this ROV could have a fully autonomous mode where it could follow trajectories set by the user. This electronics platform can serve as a platform for the development of autonomous ROV control systems.

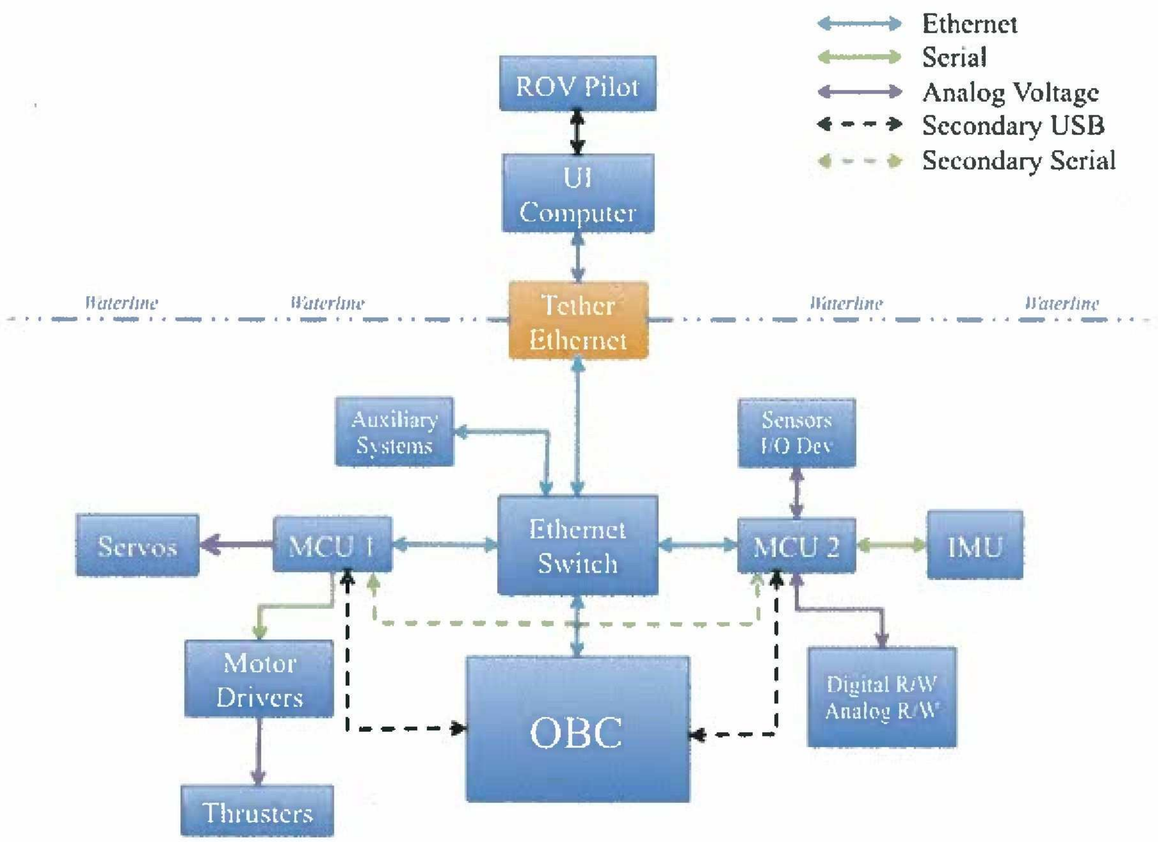

Figure 15: 2012 ROV On-Board Communication Network

• OBC	On Board Computer (single board computer)
• MCU 1	Microcontroller 1 (electromechanical systems)
• MCU 2	Microcontroller 2 (sensor data collection)
• IMU	Inertial Measurement Unit (accel, gyro, mag)

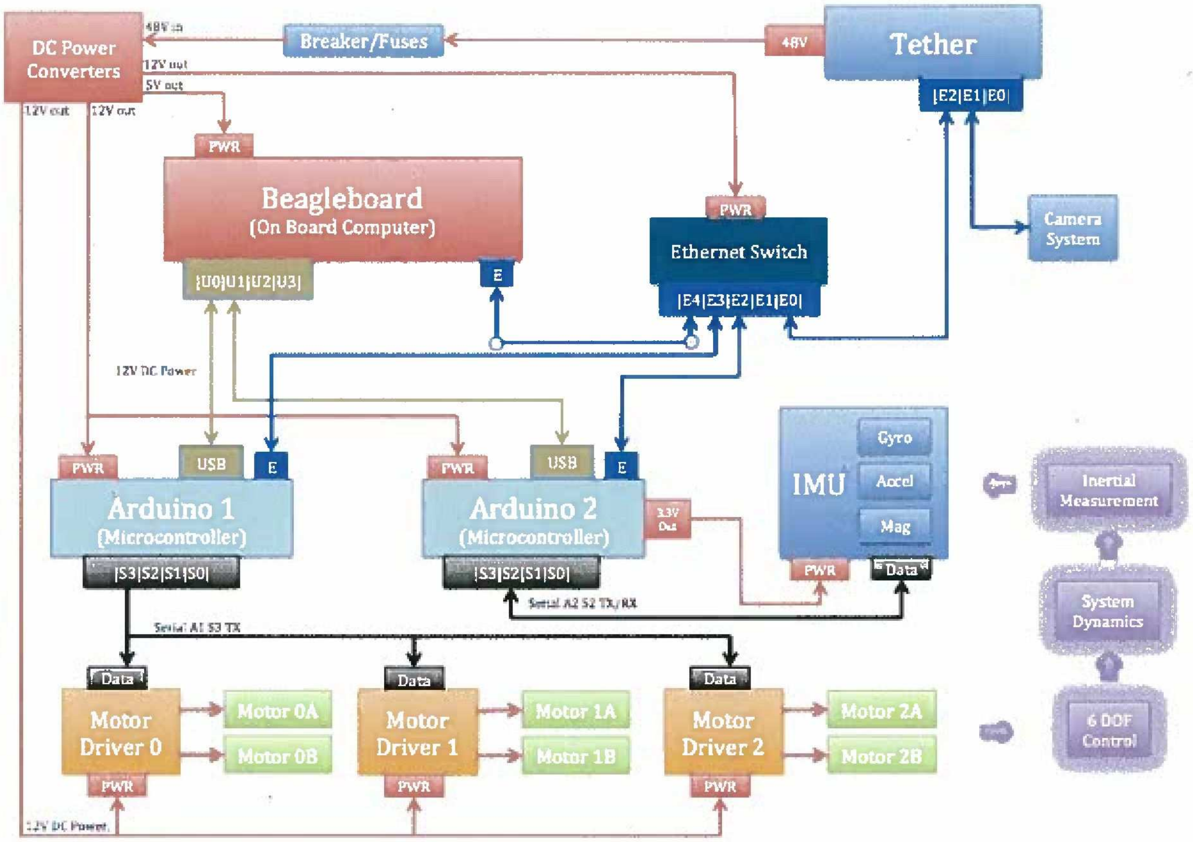

Figure 16: Schematic showing connections between electronics

6.6 Cameras

The camera subsystem experienced many revisions throughout the design and testing process, however each iteration kept the camera components completely independent from the rest of the system. This is because the large bandwidth requirements of three high-definition uncompressed video streams could potentially interfere with other traffic in the data network.

To keep the system simple and reliable, three USB extender cables, one for each camera, travel through the tether to connect the cameras to the operator's computer. This approach also lowers power consumption when compared to another common technique, which plugs the cameras into an on-board computer and in-turn transmits the video data over Ethernet.

In addition to providing a 3D display to the operator, data from the two forward-facing cameras can be analyzed by software to approximate the distance of objects. This data can be used for collision detection when an operator is driving the vehicle, but is significantly more important for autonomous operation. In the future, the software may be expanded to estimate the vehicle's position underwater similar to how a GPS provides cars with position information. The IMU alone is not accurate enough to provide position information, and these improvements to the software would allow the vehicle to be full-autonomous.

6.7 Fixtures for MATE Competition Tasks

6.7.1 Manipulator Arm

A manipulator arm, shown in Figure 17, was purchased with 2 degrees of freedom. The arm is able to swing vertically and the claw can open and close. These degrees of freedom were chosen to reduce the need for whole vehicle movement during complicated grasping tasks. The control arm was tasked to transplant the PVC end caps with pipe cleaners, which simulate endangered coral on the *SS Gardner* shipwreck. The simulated sensors, described in Section 6.7.5, were incorporated into the arm's mounting points to reduce the number of objects extending off the vehicle's bow.

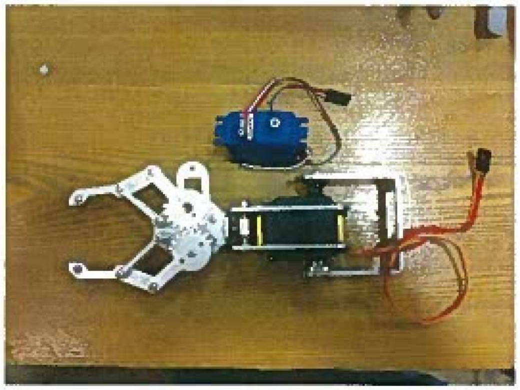

Figure 17: Manipulator arm with servo motor

6.7.2 Fuel Extraction Device

The fuel extraction system chosen, shown in Figure 18, was easy to make and flexible. It consisted of two cones attached to hollow cylinders. The cones allowed the vehicle to descend onto the fuel tank without needing to do so extremely accurately. Sections of brass tubing were placed in the center of the hollow cylinders so that they could penetrate into the petroleum jelly while the vehicle was descending onto the fuel tank. The ends of the brass tubing were capped and holes were drilled into its sides so the jelly would not enter the tubes as easily while still allowing the fluid to enter or exit. Two 1.5 liter bladders will be stored on the chassis for the storage of salt water and fuel. A small pump was used to push the salt water into the fuel tank and force the fuel into the second bladder. By modifying the size of the tubing connecting the pump to the fuel extraction device, various flow rates could be achieved which allowed for a lot of tuning options so that the salt water would not flow into the fuel tank too quickly. The bladders chosen also had approximately three times the capacity of the fuel tank so that mixing within the fuel tank could be tolerated.

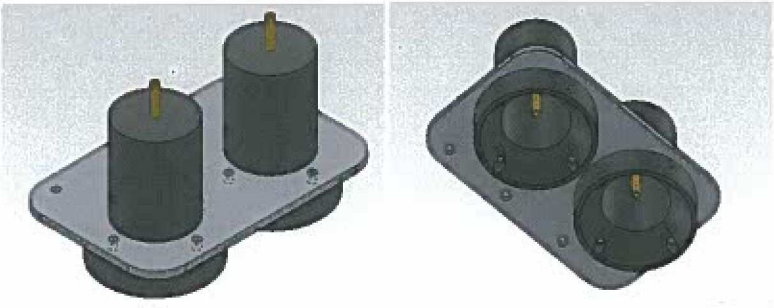

Figure 18: Top view (left) and bottom view (right) of fuel extraction device showing brass tubing used to penetrate petroleum layers. The cones are shown in the bottom view and are inside the hollow cylinders

6.7.3 Fuel Tank Capping

A system was designed to simultaneously cap both the inlet and outlet of the fuel tank, as shown in Figure 19. Two PVC pipes acting as guides and a metal bar were used to hold the caps in a fixed position on the end of the PVC pipes. The metal bar was used to keep the fuel caps from falling out of the PVC guides. When the fuel has been completely removed from the tanks, a pins on the front of the device will be pushed in, which will allow for the spring to push the metal bar away from the PVC guides. With the metal bar out of the way, the fuel caps will be released and able to attach to the end of the fuel tank inlet and outlet. The fuel caps will attach to the VELCRO on top of the fuel tank inlet and outlet, essentially sealing the fuel tank.

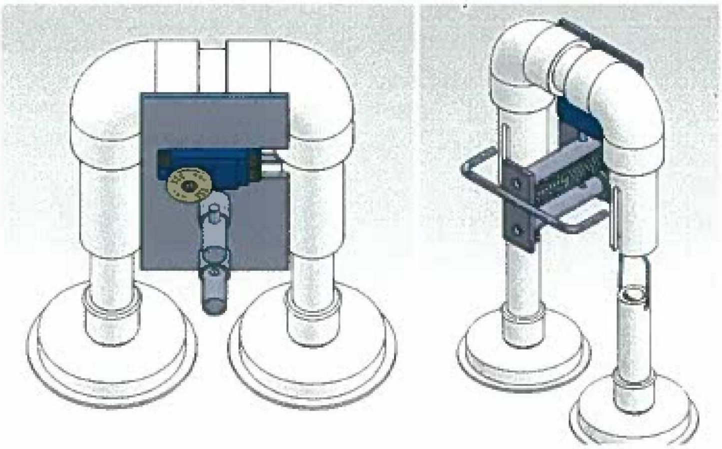

Figure 19: Front (left) and back (right) views of capping system, showing servo and pin system as well as spring to release sealing caps

6.7.4 Lift Bag System

The lift bag will be attached to the bow using a carabineer and pin release mechanism, as shown in Figure 20. The lift bag will be rigidly attached to the mechanism so that it is able to inflate vertically. The carabineer will be pushed against the U-bolt on the mast, which would lock the U-bolt to the carabineer. With the connection made, the ROV is able to maneuver the mast into its designated area. The carabineer will become detached from the ROV by using a servo to pull a pin. This mechanism was determined to be the safest way for the lift bag to detach from the ROV. This system allows the ROV to maneuver the mast without having to utilize the small control arm and allows for a way to easily detach the lift bag from the ROV. The servo motors on the control arm would not have been able to endure the stress of lifting the heavy mast without the risk of stripping their fragile gears.

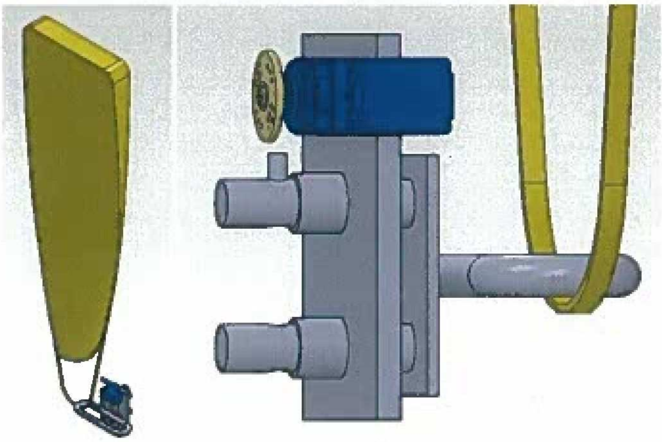

Figure 20: Lift bag system and connection to ROV

6.7.5 Sensors

The simulated fuel tank sensors were designed using a 12.7mm diameter plastic, spring loaded, toilet paper roller and a 12.7mm x 31.75mm PVC slip bushing, as shown in Figure 21. Attaching the toilet paper roll to the bushing allowed for an extended sensor when no force was applied. The spring allowed for the sensor to be in constant contact with the fuel tank in the event that the ROV became slightly perturbed during the testing procedure. The design of the metal detector was kept simple in order to increase reliability. Therefore, a strong magnet was hung from the simulated sensor such that it would be able to freely travel to a close by metal surface, alerting the camera operator that the debris being examined was metal. Orientation was simply determined using an analog compass. The compass was placed in front of the camera housing. This design was selected based on its simplicity and the projects time frame.

Figure 21: Simulated senor made of toilet paper roll holder and PVC end cap

7.0 FABRICATION

7.1 Methods and Machines Used

Many of the ROV parts were machined by team members at the Kingsbury Mechanical Engineering Machine Shop. Parts were primarily machined using a mill or lathe. The electronics capsules and thrusters were mainly fabricated using a lathe. The frame components, camera box and center electronics box were produced using a mill.

Two clear shells for each of the electronics capsules were made from a single extruded tube of LEXAN. Using a horizontal band saw, the LEXAN tube was cut into two approximately equal length sections. A lathe was used to make the two tubes precisely equal in length. The inside of each tube was eccentric and had to be rounded out using the lathe. This inside roundness was required for properly mating an O-ring to the inner surface. The rounding process removed anywhere from 0 to .05 inches of material from the tube's wall and extended an inch into each end of the tubes.

The end caps for each tube were created from a single round stock of aluminum. First, O-ring grooves and lips, for one cap, were cut into the end of the stock using a lathe. The stock was then transferred to the horizontal band saw where an oversized cut for the end cap was made. The lathe was then used again to clean up the rough cut from the saw and to finalize the thickness of the cap. These initial processes were repeated for the remaining end caps. Once all end caps were completed in this fashion, pilot holes were drilled into them using a mill. A centering tool was used to find the exact center of each cap before drilling the pilot holes. Using the guidance of the pilots, thru holes were drilled into the end caps.

Each L-channel for the frame was cut from two stock L-channels using a horizontal band saw. The cut surfaces at each end of the L-channels were cleaned using a mill. An edge finder was then used to find the cleaned surface, from one of the newly cleaned channels, and set the location as a zero reference point. A stopper fixture was implemented so that each channel was placed up to the correct reference point for drilling holes.

The camera and center boxes were made from a single 4 inch by 6 inch by 12 inch extruded aluminum box beam with a thickness of 0.25 inches. Each box was roughly cut to length using a horizontal band saw. A mill was used to size the boxes to their correct dimensions while cleaning the rough edges left by the saw. An edge finder and stopper were used to set a reference point. Holes were then drilled into each box using the mill.

Caps for the boxes were cut from two 12 inch by 12 inch LEXAN sheet using a vertical band saw. The lids were then stacked and held together by clamps so that they could be worked on all at once. The roughly cut edges were then cleaned up using a mill. An edge finder in conjunction with a stopper was used to set a zero reference point. Holes were drilled into all of the caps simultaneously using the mill. The clamps were then taken off and gasket lips were then milled into the caps.

The fabrication processes for the motor housings were similar to the electronics capsules. Motor casings were cut from a single extruded aluminum tube using a horizontal band saw. The edges and inside of each tube were cleaned and sized using a lathe. End caps for the motor housings were made in the same fashion as the electronics capsule caps. Holes in the motor casings were drilled out using a mill.

7.2 Tolerances

Tolerances for the electronics capsules and motor housings were within .001 to 0.005 inches, depending on the application. Tight tolerances were required for properly mating O-rings and lip seals. Holes in the frame's L-channels were also held at a tolerance of 0.005 inches since the machining for the LEXAN frame members were outsourced. Tolerances for the camera and center boxes were 0.005 inches due to the use of gaskets and bulkhead fittings.

8.0 ROV TESTING

8.1 Benchmark Testing

Waterproof testing of all components on the ROV occurred before any valuable electronics were added to ensure no damage. The motor assembly housing was tested for waterproofing before the motors or gearboxes were added. The thruster was submerged under eight feet of water for 24 hours. The electronics capsules were initially submerged under eight feet of water for 10 hours. A wooden cradle, with lead weights was used to sink each capsule. A second test was performed in 20 feet of water for 16 hours to ensure absolutely no leaking at the maximum depth of the MATE Competition pool. Figure 22 shows a capsule under eight feet of water.

Figure 22: Electronics capsule attached to weights at bottom of Tow Tank in Jere A. Chase Ocean Engineering Laboratory

Thrust testing was carried out using a see-saw rig to determine if the motor and propeller assembly was able to produce enough thrust. A thruster was attached to a vertical aluminum rod, which was then attached to the arm of a see-saw. A weight was then hung off the other side of the see-saw using a taught fishing line. The weight was placed on a calibrated scale. Thrust from the motor was measured by the reading of the scale as the weight was lifted or lowered. Figure 23 shows the see-saw assembly.

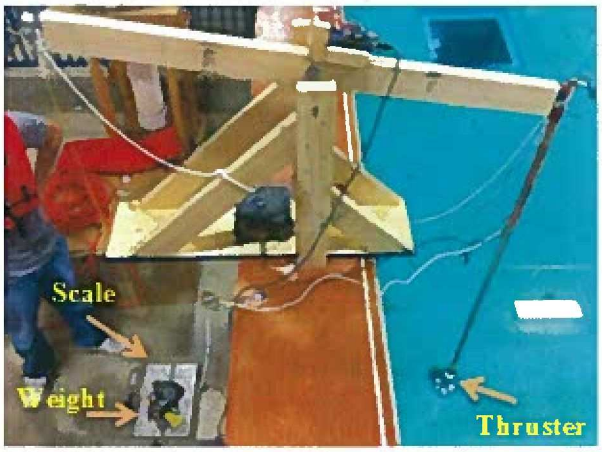

Figure 23: See-saw thruster testing assembly

The PID controls system was also testing using the see-saw assembly shown in Figure 23. The IMU was placed at the pivot point of the assembly, as shown in Figure 24. Mass was added or removed from see-saw arm, opposite from the thruster end. The PID control system was tested by having it control the motor thrust such that the see-saw arm was balanced horizontally.

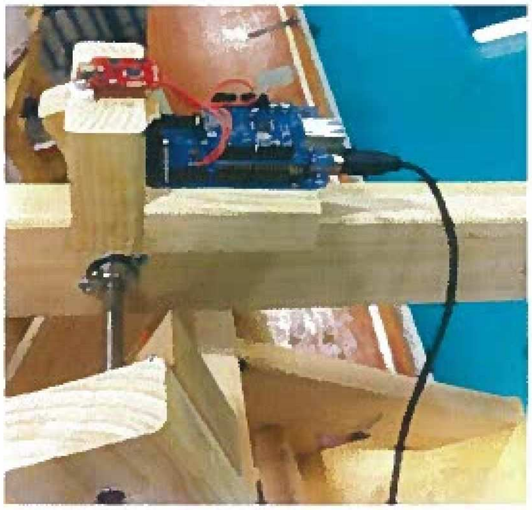

Figure 24: IMU placed at pivot point on see-saw assembly

Camera and data communications were tested using the 75ft tether. All three cameras were tested simultaneously at 1080P resolution with a refresh rate of 24Hz. Control of the motors and IMU communications were also tested over the full length of the tether.

Testing of the power converters were performed prior to submersing the ROV. A 30amp fuse was placed in line between the 48V power supply and VICOR power converters. All electronics were initially disconnected from the power converters. Electronics were connected to the convertors and tested individually. All electronics were finally connected once verification of appropriate power conversions was achieved.

8.2 Integrity of Waterproofing

Testing and verifying the integrity of the waterproofing measures was a critical part of testing the ROV. Because of the importance of ensuring the waterproof properties of the vehicle, every watertight compartment was tested multiple times before any of the sensitive and expensive electronics were added. These compartments were tested by sinking them down to the bottom of the 20 foot deep Engineering Tank in the Jere A. Chase Ocean Engineering building for several hours. As the compartments were being brought back to the surface a careful examination was done to track the origin of any bubbles in an effort to discover the origin of any possible leaks. While the main electronics tubes proved to be very reliable from the beginning, the camera box and center box were more challenging. Several different sealing systems had to be tested and perfected before the seal could be confirmed successful.

8.3 Competition Task Testing

Once all fixtures for the MATE Competition tasks are attached to the ROV, testing of each component will take place. Each mechanism will be tested by performing the tasks described in the mission tasks for the International competition. Once each component is tested and deemed completely operational, the ROV will be tested and timed with exactly what will happen at competition many times.

9.0 COSTS

Because there was not a UNH ROV team last year, this year's team was left to start from scratch with budgeting. The team created a sponsorship packet to ask for donations from businesses and was very successful in receiving donations. An estimated budget for the entire project was laid out at the beginning of the year and the team has tried to stick to it. An active spreadsheet of all expenses has been updated with every purchase made by the team. Future UNH ROV teams will have sponsors and complete budgeting information to use for their projects.

9.1 Cost Breakdown Chart

System	**Expense [USD]**
Propulsion System (motors, speed controllers, waterproofing, propellers, gear drives, aluminum)	$2,000.00
Chassis (polycarbonate plates, aluminum stock, polycarbonate tubes, aluminum plates)	$1,000.00
Electronics and Controls (Beagle Board, Arduinos, IMU, Cameras	$1,100.00
Tether Materials (Braided Sleeve, Wires, Cables)	$325.00
Mission Task Mock Up Course Materials (PVC, Hardware, etc)	$200.00
Travel (Flights, Hotel, Rental Car, Shipping ROV) ESTIMATED	$7,000.00
Miscellaneous (Waterproofing, Mission Task Equipment, Fundraising Supplies, Team Shirts, Presentation Poster, Banquet, Computers, MATE Competition Entry Fee)	$4,000.00
Estimated Total Expenses as of 4/27/12	**$15,625.00**

9.2 Donations

Donations	**Amount**
OE Department	2,000.00
CEPS Dean	2,000.00
Professor Thein	500.00
PNS	500.00
Burndy	7,950.00
Parent's Association	2,000.00
ME Department	900.00
Todd Gross	200.00
BAE	1,500.00
Jay S. Smith	100.00
NCMA	500.00
IFPTE	500.00
CACI	500.00
Total	**19,150.00**

10.0 DISCUSSION

10.1 Outlook

UNH ROV has the potential to be a something more than a senior design project. Designing and building an ROV requires a well-organized, self-motivated, and interdisciplinary team. Because the importance of modularity was stressed in the early stages of design, next year's team will inherit designs and system configurations that can be modified, refined, and perfected. They will also have this year's ROV, which will allow the electrical, software, and controls sub-groups to develop their systems while the mechanical teams designing and building the next ROV.

This year's team designed and built the ROV with six Mechanical Engineering students and one Computer Science student. Because the electronics system was built as a platform, there will be more work for electrical engineering, computer engineering, and computer sciences students next year.

After the 2012 MATE ROV Competition, UNH ROV will leave this year's ROV to the UNH Ocean Engineering Department to fulfill its secondary purpose as a platform for ROV controls and graduate level research and development. The ROV will be under the direct supervision of Professor May-Win Thein and Professor R. Swift. Also, we encourage Professor Thomas Weber at the Center for Coastal and Ocean Mapping (CCOM), in Chase OE Lab, to use our ROV for his advanced research in Acoustics. We ask that next year's team make NO physical modifications to the 2012 ROV without the direct permission from Prof. Thein, Prof. Swift, Firat Eren, or 2012 ROV team members.

10.2 Conclusion

A fully functional ROV was produced as of the submission of this report, shown in Figure 25. Future work on the vehicle, between the 2012 graduation and the MATE competition, will involve finalizing all designs, fabricating fixtures for the MATE competition, and the production of a detailed technical manual for the ROV. This year's team has met all required deadlines set by the TECH 797 course, the MATE competition, and deadlines and standards set by the team itself.

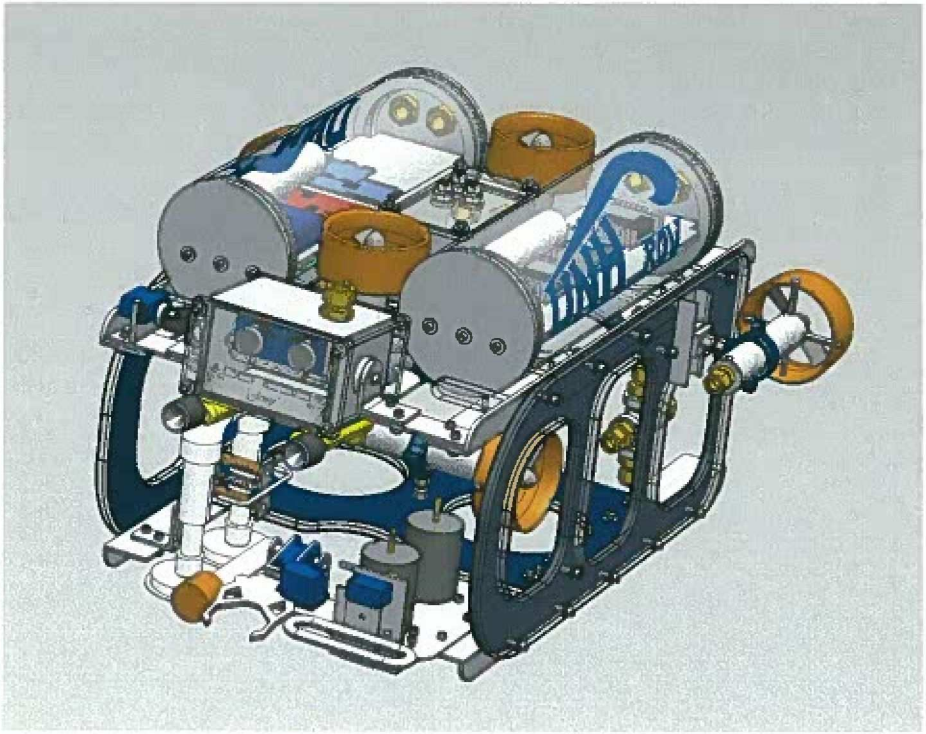

Figure 25: Final SolidWorks render of completed ROV

ROV's are an application of advanced marine robotics. Future development of ROV's will most likely include the integration of more sophisticated control systems, 3D cameras, and autonomous capabilities. University level research is slowly becoming an integral part of the development and refinement of ROV technologies.

We believe that the University of New Hampshire has the potential to be the leader in university level research of ROV technologies such as Autonomous Control Systems, Imbedded System Integration, Communications, 3D Visualization and Spatial Mapping Software, and ROV Manufacturing and Financial Planning. Our ROV stands as a symbol of the University of New Hampshire's long tradition of dedication, pride, and excellence.

11.0 ACKNOWLEDGEMENTS

11.1 Advisors

The technical challenges associated with the design and fabrication of a fully functional ROV requires guidance from individuals who are *experts* in their fields. This year's team has been lucky to have two Advisors, Professor May-Win Thein, specializes in the area of System Dynamics and Control, and Professor M. R. Swift, who specializes in the area of Mechanics and Ocean Engineering. Their dedication and virtually limitless knowledge of their fields was an essential to the success of UNH ROV.

This year's team was also lucky to have a Ph. D. Student Advisor Firat Eren, who is researching ROV Controls. His help with the development of this year's ROV Control system was crucial as he led team members in the study of 6 Degree of Freedom ROV Control Systems.

11.2 Sponsors

The UNH ROV Team extends many thanks to our generous sponsors for the 2011-2012 academic year.

- Burndy
- BAE Systems
- Ocean Engineering Department
- Sea Grant
- CEPS Dean's Office
- NCMA
- IFPTE
- CACI
- UNH Parent's Association
- Portsmouth Naval Shipyard
- Todd Gross
- May-Win Thein
- Jay S. Smith

11.3 Team Member Contributions

Matthew W. Normandeau

Co-Captain

Design and Build Contributions:

- Dynamic software based mechanical system modeling
- Development of 6 DOF ROV control system
- Design of ROV communications system
- Development ROV electronics and controls research platform
- Integration of electromechanical and computer systems
- Embedded systems
- Electronics system architecture
- Design of electrical systems

Special Contributions:

- Director of Technology
- Director of Technical Documents
- Chief Document Content Editor
- Research in 6 DOF ROV control systems
- Liaison between mechanical and software sub-groups

Articles Written:

TECH 797 Final Report

- 1.0 Introduction, 3.1 Design Criteria, 4.0 Modularity, 5.0 System Design, 6.4 Controls, 6.5 Electronics, 10.0 Discussion

MATE Report

- Controls
- Electrical Schematics

Articles Edited:

TECH 797 Final Report

- 1.0 Introduction, 3.1 Design Criteria, 4.0 Modularity, 5.0 System Design, 6.4 Controls, 6.5 Electronics, 10.0 Discussion

MATE Report

- Controls
- Electrical Schematics

Khanh Nguyen

Co-Captain

Design and Build Contributions:

- Thrusters fabrication and assembly
- Power conversion wiring
- Waterproofing of camera box, center box, capsules and motors
- Camera and center box design, fabrication and assembly
- Camera fixture design and assembly
- Tether design, fabrication and assembly
- Electronics tubes design , fabrication and assembly
- Frame design, fabrication and assembly
- Simulated sensor design, fabrication and assembly
- Lift bag system design, fabrication and assembly
- Fuel tank capping design, fabrication and assembly

Special Contributions

- Liaison between team groups and Portsmouth Naval Shipyard
- PID controls and thruster testing
- Waterproof testing
- Prepared and Assembled ROV for Open House and URC
- Parts ordering
- Website builder and updater
- Logo designer
- Shirt Designer
- Weekly accomplishment report
- Obtained Vicor and Todd Gross sponsorship

Articles Written:

- Tech 797 Final Report
    - 6.6 Fixtures for MATE Competition Tasks, 7.1 Methods and Machines Used, 7.2 Tolerances, 8.1 Benchmark Testing
- MATE Report
    - Abstract, Design, Chassis, Electronics Capsules, Cameras, Manipulator Arm, Fuel Extraction, Fuel Tank Capping, Lift Bag System, Design Safety Features and Precautions, Trouble Shooting, Future Improvements, Reflections on and Project Experience, References, Acknowledgments
- Sponsorship Packet

Fall Open House and URC Poster

Mike LeVeille

Contributions:

- Director of Software
- Chief Programmer
- ROV control system software
- ROV embedded systems software
- ROV network communications software
- Development of 3D visualization software
- 6 DOF ROV IMU data based computer model
- ROV User Interfaced

Articles Written:

TECH 797 Final Report

- 6.6 ROV SYSTEMS – Cameras

Articles Edited:

- 6.6 ROV SYSTEMS - Cameras

Raymond Jones

Design and Build Contributions:

- Thrusters design , fabrication and assembly
- Thrusters mount design and assembly
- Power conversion wiring
- Waterproofing of camera box, center box, capsules and motors
- Camera and center box assembly
- Electronics wiring
- Camera fixture fabrication and assembly
- Tether design, fabrication and assembly
- Electronics tubes design , fabrication and assembly
- Frame assembly
- Fuel extraction design
- Lift bag system design

Special Contributions:

- PID controls and thruster testing
- Waterproof testing
- Prepared and Assembled ROV for Open House and URC
- Parts ordering
- Obtained Sylvester Sheet Metal sponsor

Articles Written:

- Tech 797 Final Report
    - 6.3 Thrusters
- MATE Report
    - Thrusters
    - Cameras

Articles Edited:

- MATE Report
    - Thrusters

Thomas Provencher

Design and Build Contributions:

- Thrusters design, fabrication and assembly
- Power conversion wiring
- Waterproofing of capsules and motors
- Camera and center box design and assembly
- Camera fixture design and assembly
- Tether design, fabrication and assembly
- Electronics tubes design , fabrication and assembly
- Frame design, fabrication and assembly
- Fuel extraction design, fabrication and assembly
- Claw design and assembly

Special Contributions

- Liaison between Burndy
- PID controls and thruster testing
- Waterproof testing
- Prepared and Assembled ROV for Open House and URC
- Parts ordering
- CAD model updater
- Obtained Burndy sponsorship

Articles Written:

- Tech 797 Final Report
    - 8.2 Integrity of Waterproofing
- MATE Report
    - Cameras, Fuel Extraction
- Sponsorship Packet

Articles Edited:

- MATE Report
    - Abstract, Design, Chassis, Electronics Capsules, Cameras, Manipulator Arm, Fuel Extraction, Fuel Tank Capping, Lift Bag System

Alexandra Washakowski

Chief Finance Officer

Design and Build Contributions:

- Frame design and assembly
- Tether assembly
- Claw design
- Competition setup assembly

Special Contributions

- Accountant
- Travel manager
- Special events coordinator
- Team accessories ordering
- Prepared and Assembled ROV for URC
- Parts ordering
- Obtained Parents Association sponsorship
- Shirt Designer

Articles Written:

- Tech 797 Final Report
  - 2.0 MATE Competition, 3.2 MATE Specified Capabilities, 6.0 ROV Systems
- MATE Report
  - Budget
- Sponsorship Packet
- Fall Open House and URC Poster
- CEPS Open House Presentations
- Monthly TECH 797 Reports and PowerPoints

Articles Edited:

- MATE Report
  - Abstract, Design, Chassis, Electronics Capsules, Cameras, Manipulator Arm, Fuel Extraction, Fuel Tank Capping, Lift Bag System
- Tech 797 Final Report
  - Entire Report

Matthew Mazzola

Design and Build Contributions:

- Frame design and assembly
- Competition setup assembly
- Fabrication of various parts of ROV

Special Contributions

- Prepared and Assembled ROV for URC

Articles Written:

- Tech 797 Final Report
    - 2.0 MATE Competition

Articles Edited:

- Tech 797 Final Report
    - 2.0 MATE Competition

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