SEACAT 1.0

UNH ROV TEAM

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Abstract

The UNH ROV team is an interdisciplinary engineering team made up of 9 engineering seniors graduating from the University of New Hampshire. The 7 mechanical engineers on the team worked very closely with the 2 electrical engineers to design and build the ROV, Seacat 1.0, for UNH's inaugural performance in the 2009 competition. Seacat 1.0 was designed to be a large stable vehicle able to complete all of the 2009 mission tasks, while providing a versatile core design that can be used as a launching point for use in the future. To address the individual missions the project was modularize into several separate sections, split up by vehicle components and systems. Each section had one member of the team dedicated to oversee the progress and development of that particular section. Though there was a captain for each section, all team members of the team worked together to accomplish goals so that no one person was responsible for any task. The mechanical components were divided into the frame, buoyancy, propulsion, tools, and tether/control shack. The electrical focuses were on the wiring and power needs, as well as developing a software program to be integrated into the controller to provide a PWM output to the thrusters. The vehicle has gone through many redesigns and modifications following the testing stages and trial runs, resulting in a reliable final vehicle that meets all of the initial goals set by the team at the start of the project.

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Design Rationale

In order to complete the four mission tasks the Product Design Specification (PDS) shown below was created, which lists the things that the vehicle must have or do in order to be competitive. The ROV was then broken up into several sub sections and the design spiral shown below in Figure 2 was followed to create the initial design. To assist in the design process decision matrices, failure mode effects analysis, and criticality analysis were used.

Needs
Precision thrusters and control system
Video feedback into control system
Ability to turn hand wheel
Ability to carry and retrieve ventilation hose
Ability to open and close hatches and turn valves
Ability to transport ELSS pods
Ability to mate
Must pass safety inspection

Figure 1 - PDS

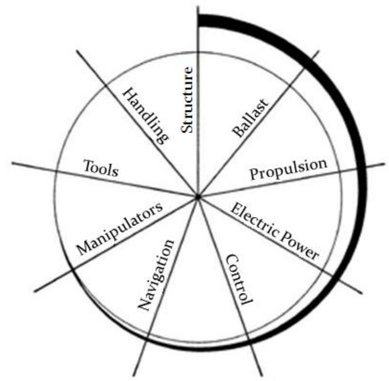

Figure 2 – Design Spiral

Mechanical

Frame

Following the design spiral, the first decision was determining the frame type. Through a process of benchmarking it was discovered that there are three commonly used designs: open, closed, and hybrid frame designs. The open frame is cheap and easy to manufacture, however experiences considerable drag while moving through the water. The closed frame design greatly reduces this drag, however is more expensive and difficult to manufacture. A hybrid frame was chosen for the Seacat 1.0 design, as it is relatively inexpensive, reduces the risk of leaks, and produces very little drag.

To determine the frame material several different options were compared in a decision matrix, shown in Figure 3 to the right, where cost and manufacturability were the most heavily weighted. As a result we chose PVC pipe, with a box type frame shape and cross supports that could be assembled in modular sections. It was decided to use ½" PVC, which was shown to be several times stronger than needed using FEA software.

	wt.	St	Al	Ti	PVC	ABS
Manufacturing	10	6	5	2	9	6
Cost	8	5	5	1	10	8
Strength	4	8	7	10	4	4
Density	7	2	4	3	9	9
Total Score		146	146	89	**249**	203

Figure 3 – Frame material decision matrix

Ballast

In consulting with technical advisors, it was determined that it would be best to design the ROV to be in essence neutrally buoyant, with just enough positive buoyancy that the vehicle would very slowly rise to the surface by itself in the event it becomes demobilized. The material selected to give the vehicle the desired buoyancy was chosen to be polystyrene foam, for the reasons that it is inexpensive, easily formable and closed cell, meaning that the tiny air pockets would not become filled up water and alter the buoyancy. To determine the amount of material needed a buoyancy budget was created in which all ROV component weights and air pockets were taken into account. From this information a required buoyant force was determined and equated into a volume of foam needed to be used on the vehicle. Again consulting our technical advisors, we determined that placing the center of buoyancy as far away as possible from the center of gravity on the ROV makes it the most stable, and for this reason we chose to place the foam at the very top of the ROV frame.

Propulsion

To move the vehicle through the water, a 6-DOF propulsion system was created that would allow the ROV to move fore/aft, up/down, port/starboard, and any combination of these. To accomplish this goal we employed the use of four fixed thrusters; two main thrusters (fore/aft) on the back of the vehicle, as well as one lateral and one vertical thruster mounted in tubes on the interior of the ROV.

The main thrusters are responsible for providing all of the forward propulsion and thus need to have the most power. With this in mind two Minn Kota Endura 30 trolling motors were selected. These were already waterproof, relatively low in cost, and provide a large amount of thrust. The trolling motors were modified by removing the shaft to mount them to the ROV frame. Nozzles were added around the propeller blades to increase the flow rate and provide safety protection.

Two small, donated DC motors were used for the lateral and vertical thrusters. To adapt the motors for our use it was necessary to waterproof them, attach a propeller and then mount them inside of a 6" PVC pipe section (seen to the right in Figure 4) that was then attached to the frame. Waterproofing was done with plastic shrink tape in combination with custom machined end cap containing a double lip shaft seal and grease zerk fitting.

Figure 4 – Tube thruster

Tools

In order to complete the mission tasks there are several additional components that were added to the ROV. The first is a manipulator that allows the vehicle to pick up the ELSS pods and transport them to the simulation submarine as well as open any doors, hatches, or valves that needed to be opened or turned. To accomplish these goals the team attached an approximately 30 cm section of PVC pipe to the front of the vehicle to act as a manipulator arm. To the end of the pipe there is a piece that acts as a wedge to maneuver the arm into position, while also preventing the ELSS pods from falling off while transferring them across the pool.

A motor driven rotating manipulator was incorporated to address the issue of rotating the hatch in mission 2. The manipulator extends two long prongs down into the center of the wheel and rotates a full 360 degrees until the hatch is unlocked. The motor used is a modified bilge pump, because it was already waterproof and capable of proving the small amount of torque needed. The prongs were then attached to a bar connected to the motor shaft and the entire assembly was bolted to the bottom of the frame, as shown to the right in Figure 5.

Figure 5 - Rotating manipulator

Finally, to address the challenge of transporting and retrieving the ventilation nozzle in mission 3 a funnel with a tapered vertical slit cut out of the side was attached to the side of the frame, as shown in Figure 6. Positioned at a 45 degree angle, the funnel is be capable of transporting the nozzle to the simulation submarine and placing it in the ventilation pipe. The slotted funnel also assists in guiding the nozzle back into the "holster" and carries it back to the surface to complete the mission. This holster is detachable so that it can be removed for the other missions to reduce drag.

Figure 6 - Ventilation nozzle holster

Electrical

Logitech USB Webcams are the cameras used to navigate the ROV, with Cat-5 cables connecting the cameras to a laptop, as shown below in Figure 7. The reason that the team decided to use Cat-5 cable is because it was offered to the team for a very low price. There is a large amount of attenuation over 100 feet of Cat-5 cable, so signal repeaters were used to both amplify the signal and to provide an USB connection to the laptop.

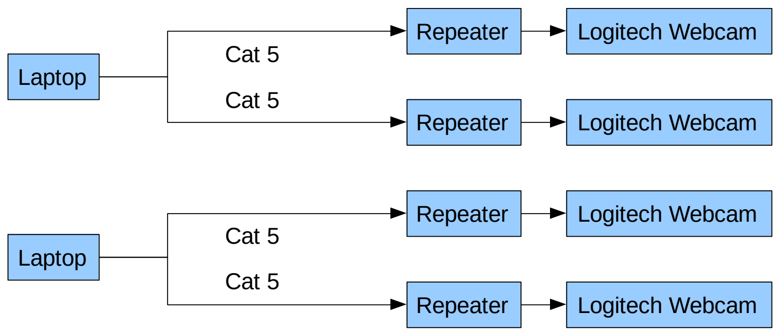

Figure 7 – Camera signal schematic

In order to pass the safety inspection, a circuit breaker was installed directly after the connection to the positive end of the provided power source. A DC to DC converter was used to step down the voltage from 48 Volts to 12 Volts.

Five H-bridges were used in the control box of the ROV. Each H-bridge consists of two NPN transistors and two PNP transistors, as shown below in Figure 8. The TIP122 and MJ11016 were the NPN transistors used and TIP125 and MJ11015 were the PNP transistors used. These transistors were selected because they are capable of handling the amount of current that the motors need. The Minn Kota motors draw a maximum load current of about ten Amps and the vertical and lateral DC motors draw a maximum load current of about five Amps. The MJ11015 and MJ11016 were used for both of these motors because they can handle up to 30 Amps. For the small manipulator motor the TIP125 and TIP122 were used because the manipulator motor will not be drawing as much current as the thruster motors. The TIP transistors can handle currents up to five Amps.

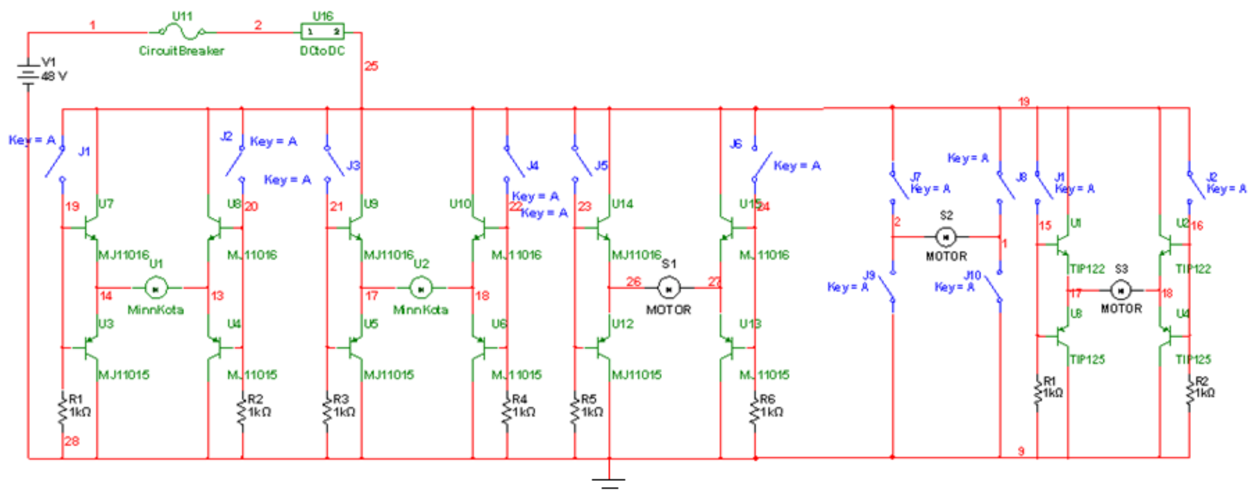

Figure 8 - Electrical schematic

An H-bridge is a circuit that is commonly used to vary the direction of a DC motor. The direction that a DC motor rotates depends on only what direction the current is going through the motor. The transistors are used as switches that can be turned on and off by giving them different voltages. When the top left and bottom right transistors are conducting, the current flows through the motor in one direction. When the top right and bottom left transistors are conducting, the current flows through the motor in the other direction. This allows each motor to be run in two directions. For one of the DC motors that were received for free, it was noticed that it did not run at a fast enough speed when the transistors were used to control it. It was also found that it ran faster if four switches were used instead of four transistors, so a four switch set up was created for that motor.

The control scheme consists of eight switches that each turn one motor in one direction and four switches that had to be paired correctly to turn one motor in two directions. Each of the eight switches was connected to the bases of one NPN transistor and one PNP transistor. The switches will toggle between 0 Volts and 12 Volts. When the voltage is at zero, the NPN transistor will not conduct and the PNP transistor will conduct. When the voltage is at 12, the NPN transistor will conduct and the PNP transistor will not conduct. A switch that has not been activated will supply zero Volts at the bases of one NPN transistor and one PNP transistor. That means that the NPN transistor is off and the PNP transistor is on. A switch that has been activated will supply 12 Volts at the bases, meaning that the NPN transistor is on and the PNP transistor is off. When the switch on the left side of the H-bridge is activated, the current flows from the top left NPN to the bottom right PNP transistor. When the switch on the right side of the H-bridge is activated, the current flows from the top right to the bottom left transistor. With the four switch system, the top left switch must be on at the same time as the bottom right switch for current flow in one direction. Current flow in the other direction meant turning on the top right switch and the bottom left switch.

This circuit will be in the control shack along with the two joysticks that contain eight switches and four additional switches. Only the two nodes that are connected to the motor will be going into the ROV. Within the tether, there are ten wires carrying power to the five motors.

Budget

ROV Budget	
Description	**Income**
ME Dept contribution	$ 700.00
ECE Dept Contribution	$ 200.00
Donation - IFPTE	$ 500.00
Donation - CACI	$ 500.00
Donation - Ian Wilson	$ 200.00
Fundraising event - Central Wave	$ 500.00
Description	**Expenses**
Kittery Trading Post - Trolling Motors	$ 261.96
Home Depot - PVC, Plexiglas	$ 153.66
Dr. Shrink - Shrink Tape	$ 16.28
Kittery Trading Post - Propellors	$ 71.20
Flex PVC - PVC Connections	$ 90.06
Happ.com - joystick	$ 13.82
Spark Fun - USB board	$ 41.74
Buoyancy Components	$ 107.83
Wire	$ 183.27
Newark Electronics - Electrical Components	$ 156.54
Cases by Source - Watertight Box	$ 43.21
Cables Direct - Ethernet Cable	$ 143.67
Cameras	$ 160.03
Supplies - Tools, Paint, Glue, Hardware, etc.	$ 298.24
Peak to Peak power	$ 166.10
Demonstration - Pizza	$ 90.50
Printing - poster	$ 79.40
Mass Maritime Academy - Housing	$ 240.00
TOTAL Expenses	$ 2,317.51

Challenges

The largest problem that the team faced was working together as an interdisciplinary team. The mechanical and electrical members of the team did not enter into the project with the same work ethics or motivation. This problem quickly branched out to all aspects of the project and had to be overcome within the first few weeks. The smaller groups that the team was originally broken down into were segregated by majors, of which some were less motivated than others. The quality of work returned by a few of the groups ended up creating more work for the other groups, which in turn created resentment from the more motivated students. The tension between the two disciplines caused inefficient meetings and a lack of desire for either side to work with the other. To resolve this issue, the groups were rearranged so that the more motivated students were paired directly in the same team with the less motivated ones to help keep them on task on a frequent basis. This decision saw immediate results, helping the entire team to work at a pace satisfactory to all without any one team having to pick up slack for another.

The largest problem faced with the vehicle was the failure of the waterproofing methods. Test procedures were used to verify that the watertight electrical components would not leak. Each component passed their tests without incident, however during later underwater tests the same component would fail. This created a need to go back and fix the problem, and begin the testing stage all over again. This situation occurred more than once, resulting in the testing phase of the project taking much longer than planned.

Troubleshooting

The team developed an in depth test verification plan to troubleshoot the vehicle. Each component and system on the vehicle was included in a very detailed test plan, with each test having quantifiable objectives and an in depth sequenced test procedure. The plan was ordered so that each component was tested individually before it was incorporated into the vehicle so that when the complete ROV was undergoing underwater tests the team was confident in the performance of the individual parts performing correctly.

Future Improvement

The largest limiting factor of the vehicle design was budget constraints. Many of the original plans had to be compromised for cheaper solutions. The main improvements that would be made to the vehicle are the vertical and horizontal thrusters and the cameras. The propeller blades and tube mounting design used for the thrusters dramatically reduced their efficiency because the tips of the blades were filed off in order to fit them into the thruster tube. While the vehicle still operates at satisfactory speeds, the use of a commercial thruster for this application would greatly improve the capabilities of the ROV. Off the shelf underwater cameras that were in the original design had to be substituted for cheap webcams placed in home-made waterproof housings. While the video feedback from the cameras is adequate, they required the use of USB to Ethernet connection signal repeaters that increased the size of the onboard watertight box and the tether. The connections often had to be adjusted, and the enclosures were one of the major areas of leakage, redesign, and repair on the ROV. A commercial product would have erased those concerns so that completion of the mission tasks could have been the main focus. On the controls side, another big improvement would be to use variable speed thruster controllers. By using potentiometers instead of switches to control the motors, it would allow the pilot to vary the speed of the motors for better precision while maneuvering the vehicle through the water.

Lessons Learned

The largest lesson learned from the project is the importance of an in depth schedule and team organization. Accountability is necessary, and without a set schedule excuses can be made and accountability can be avoided. Working with a big team often created communication problems and misunderstandings that lead to blown deadlines. The smaller groups had trouble coordinating times to meet and some parts of the project were stalled while other components were waiting to be completed. During the second half of the project there was one member of the team that was dedicated to keeping track of what each group was doing, and reminding them of scheduled deadlines, keeping the teams in coordination with each other. This organizational skill is the most universal lesson learned from the project because it can be applied to any job that the members of the team will be associated with in the future.

Description of a Submarine Rescue System

The Falcon is a tethered, remotely-operated Pressurized Rescue Module (PRM) that is part of the US Navy's Submarine Rescue Diving and Recompression System's (SRDRS) Rescue Capable System (RCS). SRDRS-RCS consists of the Falcon, its launch and recovery system, and its support equipment. This is all operated from what the Navy dubs a Vessel of Opportunity (VOO). This system is a "fly-away" system that can be operational on a variety of VOOs within hours of a distress call. It can conduct rescue operations to a depth of 2,000 feet, can mate to a submarine at a list and trim of 45 degrees, can rescue up to 16 people at a time, and can operate around the clock via the tether. In late 2012 the Submarine Decompression System (SDS), the final phase of the SRDRS program, will be implemented. This will allow the rescued submariners to remain under pressure during their transfer from the PRM to hyperbaric treatment chambers on the VOO.

There are many parallels that can be drawn between the Falcon and the ROV that has been built by this team to enter in the competition. Given the fact that the mission tasks of this year's competition are designed to mimic submarine rescue, this comes as no surprise. Like the Falcon, the SEACAT 1.0 is tethered and is propelled by several thrusters mounted at different positions on the submarine. The mating skirt is the design component that is arguably the most important in a rescue application and also makes the SEACAT 1.0 very similar the Falcon. While the vehicle being entered in this competition does not have capability to mate at a 45 degree angle, it does have to be capable of fitting its mating skirt over a simulated escape hatch, representing the same application.

http://thetension.blogspot.com/2008/10/us-navy-deploys-new-submarine-rescue.html

Reflections

Even without yet arriving at Massachusetts Maritime, it is safe to say that the experience of designing and building an ROV to enter in the 2009 MATE ROV Competition has already been a rewarding one. Perhaps the most satisfying part of the experience has been the opportunity to apply all of our engineering knowledge and work together in an interdisciplinary team to design the best possible ROV to enter in the competition. It was fulfilling to see the design become a reality as we went about building the ROV, which turned out to closely resemble the original design. The extensive testing that verified that our vehicle met the requirements provided a conclusion to our achievement. Overall the entire experience has been extremely valuable in helping our team of graduating engineers transition into the workforce. In part due to the interest generated in marine technology as a result of both entering this competition and the relationships that were formed, four of the seven graduating mechanical engineering team members have received job offers from the Portsmouth Naval Shipyard, all of whom accepted the positions. Furthermore, we have established a group of UNH students to take over the project for next year and are very excited to see the ROV Team continue to grow.

References

http://thetension.blogspot.com/2008/10/us-navy-deploys-new-submarine-rescue.html

Acknowledgements

The UNH ROV team would like to thank the MATE Center for organizing the competition and helping the team. They have always responded quickly to emails and have been very helpful and informative in their answers. The team would also like to thank members of the Deep Submergence Systems Program at the Portsmouth Naval Shipyard for their role as mentors, the International Federation of Professional and Technical Engineers and CACI for the large sums of money that helped complete the project, and Energy Resource Group Inc. that donated the use of their machine shop equipment and tools. The Ocean Engineering department graciously allowed the use of their high bay area to build and store the ROV, as well as their wave tank to test the vehicle. Hood also donated nine milk crates to the project that allowed us to recreate the competition props and prepare for the competition. The project would not have been able to be completed without the help of the many other smaller contributions of friends and family, and all others who participated in the fundraisers put on by the team.

A complete list of our sponsors can be seen below:

Marine Advanced Technology Education Center (MATE Center)
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Ian Wilson
UNH Robotics Club
UNH Mechanical Engineering Department
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