Technical Report

The University of North Carolina at Charlotte
Charlotte, North Carolina, United States

2009 MATE International ROV Competition
Explorer Class

ROVs: The Next generation of Submarine Rescue Vehicles

Team Name: The CAR ROVers
(The **C**harlotte **A**rea **R**obotics ROVers)

ROV Name: ROV NORM
(**N**avigational **O**pen-water **R**obotics **M**achine)

Zachary Miller, Team Captain/Navigator	Mechanical Engineering—2012
Patterson Taylor, Pilot	Mechanical Engineering & Physics—2012
Cory Smith, Pilot	Computer Science—2011
Brenden Hoover, Tether Man	Electrical Tech. Engineering—2011
Jesse Bikman, Airline Man	Computer Science & Mathematics—2012
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Abstract

This technical report describes the ROV Navigational Open-water Robotics Machine (NORM), as constructed by the Charlotte Area Robotics Club in order to compete in the 2009 Marine Advance Technology Education Center (MATE) International ROV Competition. NORM could be reproduced for approximately $1500. The frame is built with neutrally buoyant high-density polyurethane with positively buoyant closed-cell urethane foam on top for flotation. Propulsion is produced by six 12V bilge pump motors mounted to the frame; four motors give movement in the X-Y plane and two for the Z plane. NORM is equipped with multiple payload tools for accomplishing the given tasks efficiently. An electromagnet assembly is attached to the front of the ROV, with the capability of transporting the air valve and picking up five pods. A stationary arm, carved out of polyurethane, is equipped with a motor assembly and is capable of opening and closing various doors and handles. A mating skirt is attached to the back to a waterproofed linear actuator to help counterbalance the weight of the five pods, 10N, on the front. NORM is controlled by two joysticks, and operated by one Renesas™ board programmed in the C programming language. All electronics are located on the surface to provide reliability and easy accessibility while the ROV is in the water. NORM was designed to help in submarine rescue missions in the future so as not to put humans at risk during the rescue attempt. Humans are able to control the ROVs from a safe platform on the surface.

Team Introductions

Zachary Trevor Miller is a freshman Mechanical Engineering major. This is his second year competing in the MATE ROV International Competition. Zachary wants to pursue ROV engineering and design.

Patterson Taylor is a freshman Mechanical Engineering & Physics dual major. It is also his second year competing in the MATE ROV International Competition. Patterson is still undecided on future plans.

Cory Smith is a sophomore Computer Science major. This is his first year competing in the MATE ROV International Competition. Cory wants to pursue video game design.

Jesse Bikman is a junior dual majoring in Computer Science and Mathematics. This is his first year competing in the MATE ROV International Competition. Jesse was a late addition to the team as he developed an interest in working with the ROV project. He is the President of Charlotte Area Robotics and currently plans on entering graduate school to research Visualization Techniques.

Brenden Hoover is a sophomore Electrical Technology Engineering major. It is his first year competing in the MATE ROV competition. Brenden was also a late addition to the team. He is still undecided on future plans after undergraduate studies.

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1.0 Budget Sheet

System	Item	Qty	Donations	Purchases
Frame	Cutting Boards	3	($75)	
	L Brackets	8		$8
Floatation	Foam	1		$20
PodMaster	Electromagnet	1		$50
	Metal	1		$25
Stationary Arm	360 Pump	1		$20
	Arm Material	1	($15)	
Electronics	Renesas Boards	1	($60)	
	H-Bridges	8		$100
	Wire	3 meters		$15
	Joysticks	2		$30
	Switches	3		$15
	Control Box	1		$20
	DC-DC Converter(12-5)	1	($20)	
	Dc-Dc Converter(48-12)	1		$65
	Fuse	1		$2
Camera	Color Wide Angle	2		$100
	B/W Cameras	4		$76
	Waterproof housings	6		$40
Miss.	Fasteners			$100
	O-Rings	6		$10
	Plexiglass	Sheet		$20
Mating Skirt	Linear Actuator	1		$110
	PVC End Cap	1		$2
	Waterproof Housing	1		$7
Propulsion	1000 gph Bilge Pumps	8	($120)	$120
	Motor Housings	4		$30
	Props	8		$16
	Drive Dogs	8		$16
	Prop Adapters	8		$16
Tether	16 AWG Wire	470 Meters		$120
	Zip ties	20		$5
	Shrink Rap	1 meters		$5
	Cable Organizer	17 meters		$100
	Total		($290)	$1,263
	Total with Donations			$1,553

Travel and Housing	Accomenations	($160)	
	Gas	($300)	
	Travel	($460)	
	Total with Travel		**$2,013**
Monatry Donations	HDR Engineering	($100)	
	Zapata Engineering	($100)	
	Elm Engineering	($25)	

2.0 Design Rationale

2.1 Structural Frame

2.1.1 ROV Frame

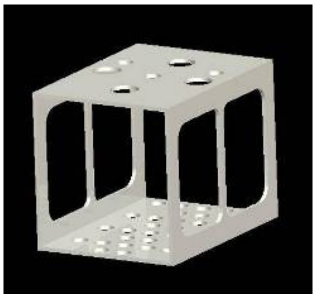

Figure 1. Pro/Engineer Frame Design

ROV NORM is made out of four sections of high-density polyurethane, which makes the size of NORM 48.5cm x 45.5 cm x 60.5 cm. Our team picked this material because it is neutrally buoyant and easy to shape. The shape of NORM is a rectangular prism. The two side panels have two rectangles cut into them for water flow, and to reduce drag when strafing left and right. The frame is attached with stainless steel hardware and has eight added L brackets for support. The top and bottom panels have circular holes cut in them to allow water flow when NORM is moving up and down. The frame material gives the ROV a professional look and an easy mounting area because of the flat surfaces on the panels.

2.1.2 Buoyancy

ROV NORM's flotation is made out of closed cell urethane foam. The foam is 98 % closed cell. The foam was fiberglassed after expansion for added support and a professional look. This foam was cheap but more than suitable. The urethane foam floats 28 kilograms per 28.31 cubic decimeters. The foam can also support 30-PSI shear strength and 50 PSI of flexural strength. Our foam has been tested down to one atmosphere, which exceeds the depth of the competition. It has also been tested in accordance with the U.S. Coast Guard Regulation #33 CFR 183.114[1]. The fiberglass also gives NORM a large hard smooth surface which allows us to recognize our sponsors.

Figure 2. Zach working on buoyancy

2.1.2 Propulsion

NORM is outfitted with eight, 12V bilge pump cartridges each rated at 1.05 L/sec (1000 GPH). Four of these motors are mounted at 30 degrees from the direction of movement and provide propulsion in the X-Y plane. These motors are each housed and mounted in custom fabricated brackets. The remaining four cartridges are centered on the machine and are mounted vertically through the flotation to provide movement in the Z plane. Each of these cartridges has been modified with shaft adaptors, drive dogs, and propellers to convert the bilge pumps into inexpensive ROV thrusters. Also, each of these eight motors operates in both forward and reverse directions and is controlled by two arcade-style joysticks. Each thruster produces 10 Newtons of force in the forward direction and 7 Newtons in reverse.

Figure 3. Thruster and custom housing

2.2 Payload Tools

2.2.1 Cameras

NORM is equipped with six cameras, three on the front, one and the back and two on the sides. Two of the cameras are color wide-angle board cameras with 460 lines of resolution and were made with the team- designed waterproofing housing. 1½ in PVC threaded fittings were used with Plexiglas and an O-ring for water tight connections. Four of the remaining cameras were made the same way but with black and white board cameras with 420 lines of resolution[2]. The cameras are mounted onto the frame with 1 ½ in PVC straps.

All cameras share the same power wires to help reduce conductors in the tether. All video conductors are inputted on a four channel color video splitter to allow for multiple cameras to be viewed on one TV monitor. Two TV monitors will be used.

Figure 4. Custom camera housing

2.2.2 Pod Master

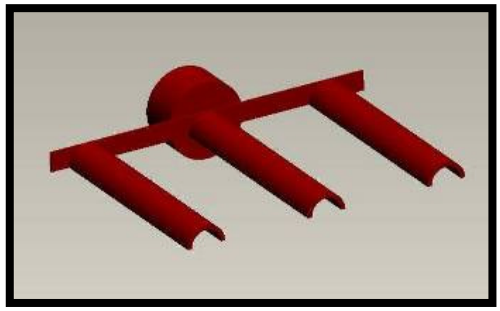

Figure 5. PodMaster in Pro/Engineer

In order to maximize efficiency in the task of pod posting, we designed a device that could easily pick up, transport, and deliver all five pods simultaneously and we called this the "PodMaster." Zinc coated iron u-bolts allowed for the use of an electromagnet, which supplied a relatively simple solution to an otherwise timely task. The PodMaster is composed of three half-round sections of 3.175 centimeter diameter steel tubing attached to a length of steel flat bar. This entire device is directly bolted to an electromagnet with carrying capacity of approximately 226 Kg. Once the three arms of the PodMaster are correctly aligned under the rows of pods, the electromagnet is engaged and left on until the ROV is aligned above the open hatch where the process is reversed. The PodMaster is operated from the control box with a simple on/off rocker switch. In addition to handling pods, the PodMaster is outfitted with an air valve assembly, which allows for the transportation of the airline to and from the surface as well as its insertion into the inlet valve connection. The electromagnet also aids in this task by means of a rod and bracket affixed to arm of the PodMaster in addition to a matching bracket that is temporarily affixed to the airline. This allows us to combine two tasks that would potentially require the use of completely different payload tools into one entirely original design.

Figure 6. Stationary Arm

2.2.3 Stationary Arm

Minimizing the amount of moving parts, or potential problem sites, was a concern and priority in designing ROV NORM. In the design stages, we also decided to combine as many necessary payload tools as possible to accomplish the given tasks. By doing this, it was possible to create a single stationary arm that would aid in the completion of various aspects of almost every task. The arm was constructed of two half-inch layers of high-density polyurethane (HDPE), which was attached and secured to the frame of the ROV with stainless steel hardware. A vertical addition to the arm was added to aid in the recovery of a pod if one were dropped or dislodged from the arms of the PodMaster. The only moving part that was installed on the arm was a single bilge pump motor that was outfitted with a length of PVC to open and close the 360 hatch for pod posting. Overall, the design and simplicity of the stationary arm provides a concise solution for accomplishing a variety of tasks.

2.2.4 Mating Skirt

A 30.5cm linear actuator was waterproofed with PVC end caps and 3 in PVC pipe. This actuator was attached to the mating skirt to protect a vital life-saving device from damage. When the mating skirt is needed for task four, the linear actuator will extend to the rear of the ROV until the mating skirt is at a distance good for mating. The variability in the distance that ROV NORM can mate with the submarine, helps in the real world circumstances when unknown problems could occur. Also when transporting the pods, the linear actuator can be extended to the rear to help counterbalance the weight of five pods when they are carried on the front. This will help shift the center of gravity back to the middle when added weight is on the front.

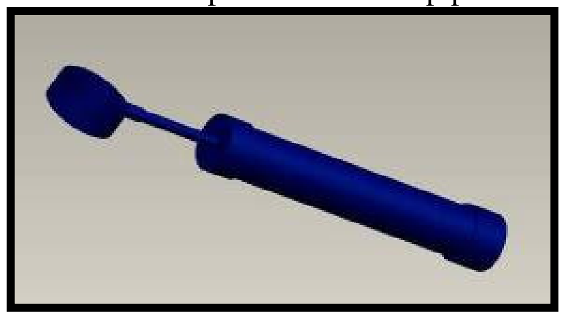

Figure 8. Mating Skirt in Pro/Engineer

2.3 Electronics

2.3.1 Tether

NORM's 17 meter tether consists of twenty-eight 16 AWG conductors. The four X-Y plane thrusters have two conductors each and are attached to the H-bridges on the surface. Two of the Z direction thrusters have their own conductors, the other two thrusters share common conductors. All of the cameras share the same power conductors and have their own video conductors. The electromagnet, 360 pump, and linear actuator each have their own positive and ground conductors. An electrical schematic for ROVs NORM electronics is located in the Appendixes A.

NORM's original tether was donated by *Sound Ocean Systems, Inc*. with eight conductors; one 18 AWG twisted pair and three 22 AWG twisted pairs. This tether was the original tether until the electronics were moved to the surface because of the reliability that the surface electronics gave us. Our conductors are bundled and wrapped with Mylar® tape followed by braided Kevlar® that is surrounded by a yellow polyurethane jacket. An electrical schematic for the old tether is located in Appendixes B.

2.3.2 Control System

Two arcade-style joysticks are mounted on a wooden box to operate ROV NORM. One Renesas™ board allows for input signals from the joysticks to be converted to output signals to the thrusters that control NORM. Two joysticks allow for programming with code schemes that can be edited more easily if a problem arises. Our team decided on two drivers for the two mission times. Our drivers did not want the same control scheme for the joysticks. We designed our code to make use of switch-case statements. If a scheme switch is in the 'up' position, person one's control scheme is activated and if the switch is in the 'down' position, person two's control scheme is activated. This gives both of our drivers their optimal control scheme.

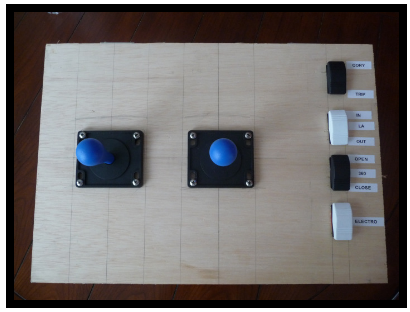

Figure 9. Control Box

2.3.2.1 Renesas™ Boards

The Renesas™ board is a demonstration board from the Renesas™ microcontroller family. They provide the interface between the joysticks and the power electronics. In the intended topside controller and bottom side power electronics layout, it provided a communication link between the topside and the bottom side. The Renesas™ board was selected due to its familiarity among the UNC Charlotte faculty and students. Since it is a demonstration board, it comes populated with switches, LEDs, and a two-line, eight-character LCD display. Other peripherals are easily accessible by soldering on wires or connectors. Because the Renesas board is being implemented as an embedded system, it does not require the design or implementation of a complete operating system, reducing the complexity and lowering the memory overhead.

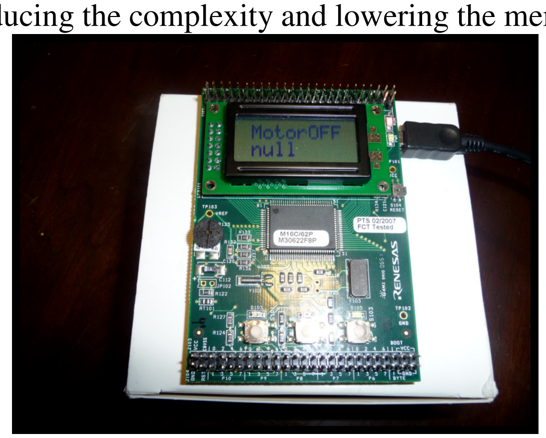

Figure 10. Renesas Boards

2.3.3 Software Flowchart

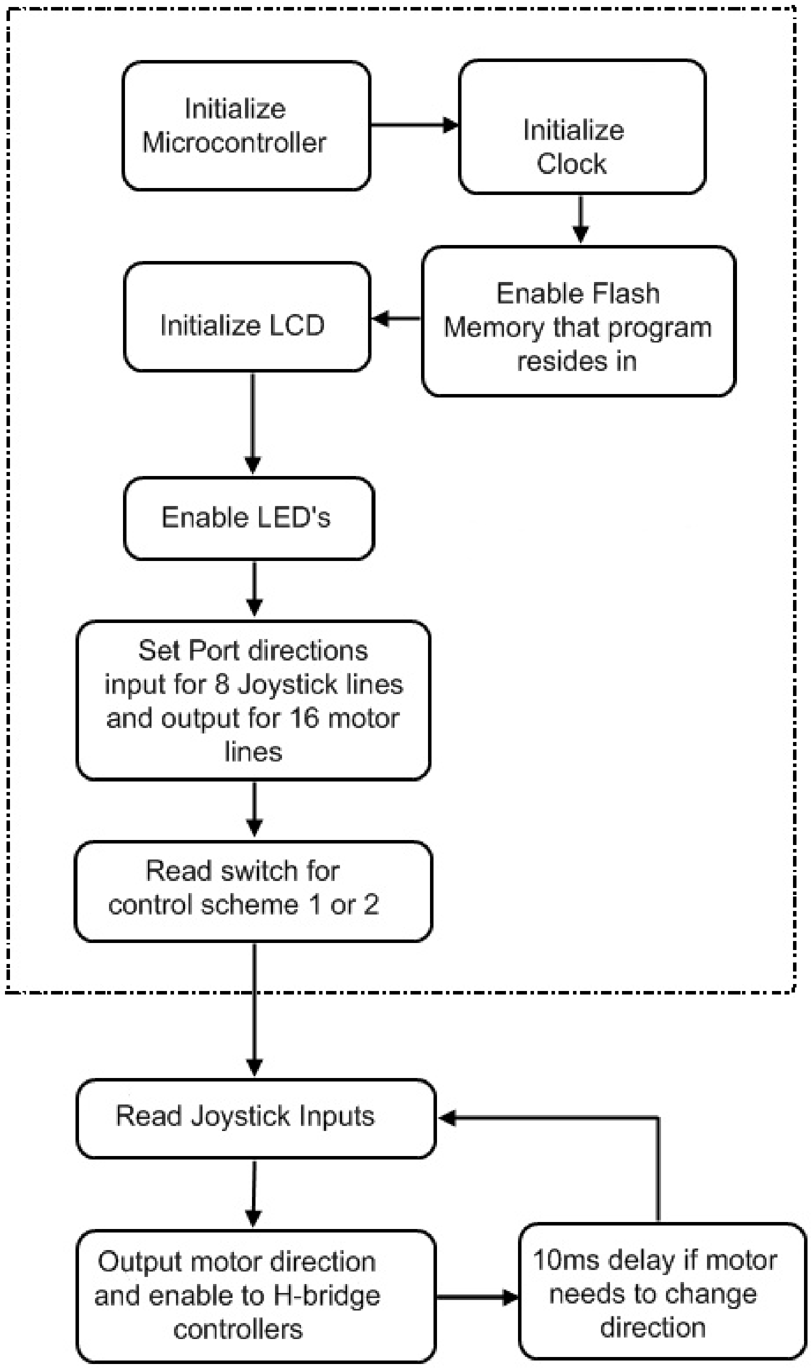

Figure 11. Software Flowchart

2.3.4 Topside Electronics

The topside electronics consist of a control box housing a DC-DC converter, eight H-Bridges, and a single Renesas™ control board. All electronics were installed on the surface for the purposes of accessibility and reliability. By positioning the electronics on the surface, we reduced the risk of operational issues. The ROV can be fixed quickly if anything goes wrong, since the control board is located at the control station. Also the Renesas™ board has a LCD screen on it for easy recognition of problems. The two joysticks are hooked up to the Renesas™ board, which controls output signals for the motors. The eight thrusters are attached to H-bridges to allow communication between the Renesas™ board and thrusters. The linear actuator and 360 motor are directly wired to momentary switches. The electromagnet is wired to another DC-DC converter, 12 V to 5 V, and then wired to a momentary switch. A wiring diagram is included in the appendix for clarification.

2.3.4.1 H Bridges

The H-bridges provide forward and reverse for the motors, but they will also allow the motors to be run at varying speeds. Although the varying speeds are not used in this year's ROV, it is a feature that can be very helpful in later versions. The H-bridges each have a 10-amp limit, which is greater than the maximum output of this year's thruster motors.

Figure 12. H-bridges on aluminum heat sink

2.3.5 Bottomside

All bottomside electronics were abandoned after extensive testing because of difficulties in accessibility and lack of funding towards fabrication or purchase of a waterproof enclosure for opening and closing for use in situations in which program code would need to be changed. NORM's initial bottomside electronics were put in place to eliminate wires in the tether and help provide a voltage closer to 12V. This would give the ROV more power and allow for a more professional appearance. Overall our decision had more positives then negatives to the current problems we encountered. The only bottomside electronics now are the payload tools and thrusters with the tether directly attached.

3. Challenges Faced

As this is the University of North Carolina at Charlotte's first year in the 2009 MATE ROV Competition, we had major issues recruiting team members and raising money. We started with two team members from the same high school ROV but we could not generate enough publicity to recruit further members. The team searched far and wide until we finally found a third member to have a complete team ready for the competition. In the process of finding members, the team found a student organization, Charlotte Area Robotics, to sponsor the team in the competition. Some graduate student members from Charlotte Area Robotics were willing to help teach the team about C programming and H-bridge design.

4.0 Troubleshooting Techniques

Our team used several troubleshooting techniques throughout the process of designing and building ROV NORM. With the current team not having progressed far enough into the engineering curriculum or having enough members to split most of the work up, a great deal of time was devoted towards learning new skills rather than putting known skills to work right away.

One problem we encountered was the waterproofing of our boxes. In the beginning our team decided to house our electronics on the ROV to eliminate the size of the tether and prevent voltage drop. With the team only having the money in their pockets and some donations the issue of waterproofing went to what was readily available at the local hardware stores. The team went through he process of troubleshooting when trying to achieve a waterproofed box.
The team tried using metal water fittings screwed into an outside electrical box with multiple layers of heat shrink over the wires. RTV (Room Temperature Vulcanized) silicon was used to help with the seal between the top and the base of the box because a suitably sized O-ring could not be found.

Much of our troubleshooting came because of limited pool time. With our ROV not being able to fit in a bath tub, the pool was the only place available to test the waterproofed housings and cameras. Our waterproofed camera housings did not leak but when the cameras were hooked up they did not have video. We had to figure out the problem while at poolside. We did not want to open up the waterproof housings, but finding the issue was not a problem with a voltage meter and patience.

5.0 Lesson Learned

Zach

Figure 13. Zach in the water with NORM

After participating in the 2008 International Competition in the Ranger division, I saw what it was going to take to compete in the Explorer class. This year I had to learn how to weld, solder circuit boards; and prepare quality engineering reports and presentations. I had a basic grasp of these skills before preparation for the competition, but I was acutely aware of the need for more intelligent and polished reports and products. Fortunately I was taught these skills by professionals during my freshmen year of engineering. I knew that I would have to dedicate a lot of time outside of class to achieve these skills to do what was needed for the competition and this is exactly what I did.

With help from graduate students, professors, and adults in the industry I eventually mastered the skills that were needed to compete at a higher level of competition. These mechanical and electrical skills meant that our team could implement the use of joysticks and custom housings on our ROV this year. One main skill I learned during my Introduction to Engineering class was how to give a professional engineering evaluation and report; this prepared me for the writing and presentations that lay ahead.

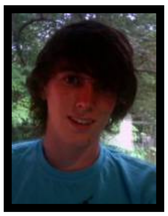

Figure 14. Patterson Taylor

Patterson

Throughout the MATE R.O.V. competition, my team and I had to learn to manage time for real world projects in engineering. Prior to this year, the core of the UNC Charlotte Team had participated in the Ranger class and the management of time with high school classes and help from faculty was much easier than the self-motivation required in the Explorer class due to becoming college students and acquiring a more rigorous schedule. With all members of the team having radically different class times, having group meetings was much more difficult. Much of the work was completed by teammates during our free time.

Programming was not a strong point of the team initially, and when we realized that there was a large voltage drop along our tether, we decided to include an onboard, computerized control system to counter the voltage drop and allow for more intuitive controls for the drivers. Building the program to handle such operations was incredibly difficult, and with the guidance of some helpful graduate students, some of the teammates and I learned to become proficient with C programming.

Figure 15. Cory controlling the ROV

Cory

When I first agreed to take part in this experience with the ROV program I was unsure what to expect. I was told that my programming expertise would be used, but the type of programming that must be used for the control schematics would have to be C programming, and I had only had experience with C++ programming. It was a difficult task to teach myself C programming on my own, but with the help of books that I acquired and the internet I was able to come up with an outline of the program. By learning C programming I was able to understand that C programming is much faster and can use a larger quantity of data in its body. This makes C programming the most efficient for accomplishing our control schemes.

6.0 Reflections

Zach

Over the past two years this competition has put two of my great passions together: water and engineering. Because I have lived at the beach my whole life, the water has always interested me. As a result of my involvement in this competition, I have been able to apply my love for engineering to this amazing underwater robotics world and in doing so, have found where I want to take my future plans. Instead of directing myself at the general world of engineering, I am now keenly focused on the marine fields and all that they have to offer.

This competition has given me the opportunity to meet many new people and network with potential future employers. The Explorer Class demands a higher level of knowledge and skills and I have risen to this challenge by exploiting local resources and embarking on a parallel educational journey: one road took the formal UNC Charlotte route and the other wound through the unknown territory of self-discovery and exploration. Such skills I learned through determination and by using my initiative were, C programming, extensive wiring and soldering, welding. My engineering focus has been mainly mechanical this year, providing me with a new challenge to learn some of the electrical engineering world. With extensive look in the electrical engineering this has made me decided to look father into the electrical aspects of engineering and maybe pursue a dual degree in Mechanical and Electrical Engineering.

Patterson

This competition has allowed me to reach higher planes of knowledge in the fields of electronics, physics, and engineering. Many of my peers and teachers have been proud of my achievements during last year's MATE competition, at which my team placed first in our region by a substantial point margin and performed well at the international competition in San Diego, California.

Participation in the ROV competition also opened up many scholarship opportunities for me and fellow teammates and possible internship positions with engineering firms or marine study organizations.

Cory

It was satisfying to teach myself, and then my peers, C programming so that they gained a better understanding of the controls and how they operate. It took a long time before I felt comfortable enough to start writing our program for the control schematics; it was a slow process. The programming aspect controlled my life for the month and it taught me the time management skills that I lacked before I began this process as I juggled school and work with my ROV assignments. This task was by far the most complicated and stressful assignment that I have had to perform and accomplishing it has made me realize that I do not want to continue in the programming profession. I am glad I had this experience before I continued my schooling in programming, and I am looking forward to seeing where my life takes me now. I am glad that I got the program to work successfully and am looking forward to getting the ROV to control and work successfully in the competition.

7.0 Submarine Rescue Mission

"Phoenix International provides manned and unmanned underwater operations, design engineering, and project management services to clients in the oil & gas, defense, and other ocean related industries worldwide. Phoenix offers its services from six regional offices and also offers plenty of capabilities to support all tasks[3]." ("Phoenix International")

In the world of underwater challenges Phoenix International, Inc. (Phoenix) is at the top of its game. Phoenix uses both manned and unmanned technologies to solve these underwater challenges with cost-effective solutions. Phoenix's clients include governments, the military, scientists, and oil & gas companies. Phoenix has ROVs that range from inspection-only to heavy work systems capable of operating in 6000m of water. Phoenix operates and maintains its private fleet of ROVs and those of the US Navy's Supervisor of Salvage and Diving.

Figure 16. Russian Submarine off of Kamachatka Peninsula

In August of 2005 the US Navy called upon Phoenix to help with submarine rescue support. A Russian submarine, Priz AS-28, was caught in fishing nests off of the Kamchatka Peninsula and the lives of seven crewmembers were endangered. Phoenix mobilized its one-Atmosphere Diving System (ADS) and the Navy's ROV Deep Drone for the rescue, also with pilot's technicians and many other personnel to help in the recovery. Over 50,000 lbs of ADS related equipment was loaded within hours of notification of the rescue. The British rescue team was the first to arrive on the scene and it cut away all fishing nets that had entangled the submarine. This successful action terminated the need for the Phoenix's ADS and the Navy's Deep Drone. Even though Phoenix did not help in the actual recovery of the Priz AS-28, the effort by Phoenix in getting to the scene within minimal time was extraordinary.

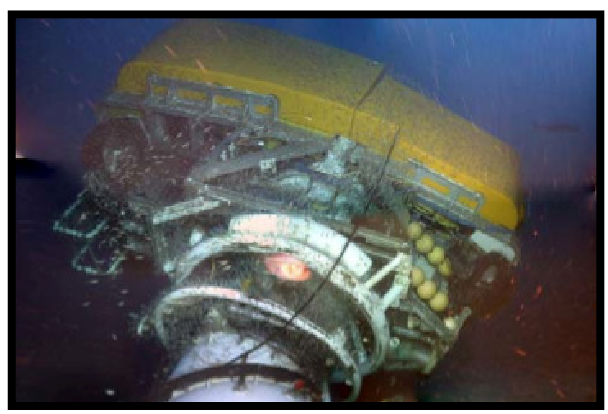

Figure 17. REMORA off of Western Australia

On June 4, 2007 Phoenix International, Inc. announced that it had successful recovered Australia's Submarine Rescue Vehicle, REMORA, off Western Australia. The 18.4-ton rescue vehicle fell to the ocean floor last December. Phoenix was completely satisfied with recovering REMORA. As a company Phoenix is not only the U.S. Navy's prime company for worldwide underwater search and recovery operations, but also for maintenance and operation of the Submarine Rescue Diving Recompression System. Phoenix was happy to play a role in supporting the anticipated re-establishment of a fellow submarine community's rescue capability. As the prime contractor for the search and rescue operations, Phoenix used the Navy's ROV, CURV III, to first examine the condition of REMORA and then to help in the recovery.

Again on June 26, 2008 Phoenix, as a prime contractor for operation and maintenance of the US Navy's submarine rescue systems, completed the successful submarine rescue, Bold Monarch 2008. During this long exercise the PRMS, Pressurized Rescue Module System, a key element of the US Navy's Submarine Rescue Diving Recompression Systems, mated with three different submarines to free 203 personnel. Phoenix was responsible for organizing and overseeing the transportation of PRMS. In this effort Phoenix support team conducted all piloting, navigating, and positioning in mating and transferring of the actual personnel. Each of the three rescue systems successfully mated with bottomed submarines, with the PRMS and NATO rescue submersible also affecting the first ever, safe transfer of personnel in water depths to 140 meters.

Recently on Wednesday April 29, 2009 in Houston Texas, Phoenix International announced the acceptance of two deepwater underwater maintenance projects in the Green Canyon area of the Gulf of Mexico. Work includes the removal and replacement of six non-wet mateable tension cables, removal of fairings, recovery of storm debris from the top of the hull, and the replacement of rigging associated with in-situ oceanographic sensors. Both projects will be helped by the M/V *Anne Candies*, a 240 feet DP II vessel long term charter to Phoenix from Otto Candies, LLC of Des Allemandes, Louisiana[4].

Figure 18. NATO

8.0 Future Improvements

One of the main improvements we would make to NORM would be with the thrusters. Following tests throughout the building process more thrusters were added to give NORM more force; however, more funding is needed to help buy ROV thrusters. *SeaBotix*'s thrusters would be an improvement for future competitions. The *SeaBoti*x ROV thrusters offer about 24 N of force at only 4 amps, while the 1000-GPH bilge pumps we are currently using offer only 5 N of force at 3 amps. Upgrading the thrusters would help to increase the speed of the ROV and lower our amps, since fewer motors would be used.

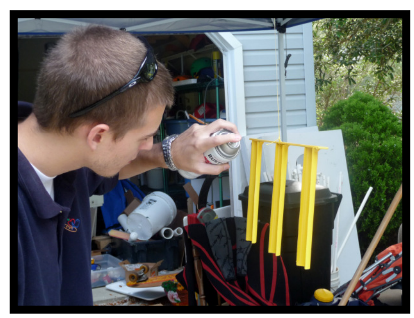

Figure 19. Cory Spray Painting

Another improvement would be to house the electronics onboard to eliminate an overly large tether. This improvement was targeted for the first two months of working on the robot, but the team could not find an affordable solution to the problem. The issue was how we could minimize the number of wires entering and exiting the box without waterproof pin connectors. With this year's thrusters not having built-on waterproof pin connectors and also not having a waterproof housing with built- in pin connectors, achieving a waterproof box that could be opened, if improvements or problems were encountered, was almost impossible with the money we had.

These two improvements have one main issue in common: money for the ROV. Although a lot of companies were contributing to some degree, none were able to provide enough financial support to enable us to make the necessary improvements. Next year's fundraising will start early in an effort to raise more money to help support the ROV competition.

9.0 Qualifying Test Photos

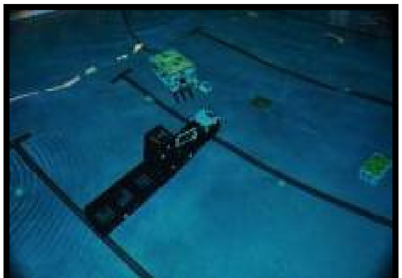

Figure 20. ROV NORM approaching the submarine

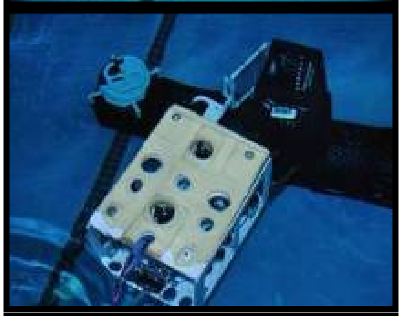

Figure 21. NORM opening the door of task 3

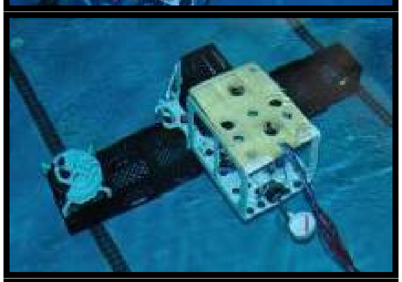

Figure 22. Another view of opening the door

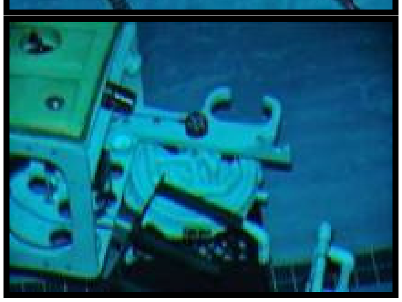

Figure 23. NORM using the stationary arm subassembly to open the hatch

10.0 References

[1] "2 Part Liquid, Expanding Urethane Foam," http://www.uscomposites.com/foam.html Accessed Apr. 12, 2009

[2] "Board Cameras," http://www.supercircuits.com/Security-Cameras/Board-Cameras/ Accessed Feb. 20, 2009

[3]Email from Timothy W. Janaitis, Director, Business Development Phoenix International, Largo, MD, May 17, 2009

[4] "News," http://www.phnx-international.us/News.htm Accessed May 18, 2009

Photo credit(Submarine Rescue Mission): Timothy W. Janaitis from Phoenix International

Figure 24. Jesse working on programming

11.0 Acknowledgements

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    Thomas Meiswinkel (Mentor)
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Zapata Engineering (Monetary Donation)
Elm Engineering (Monetary Donation)
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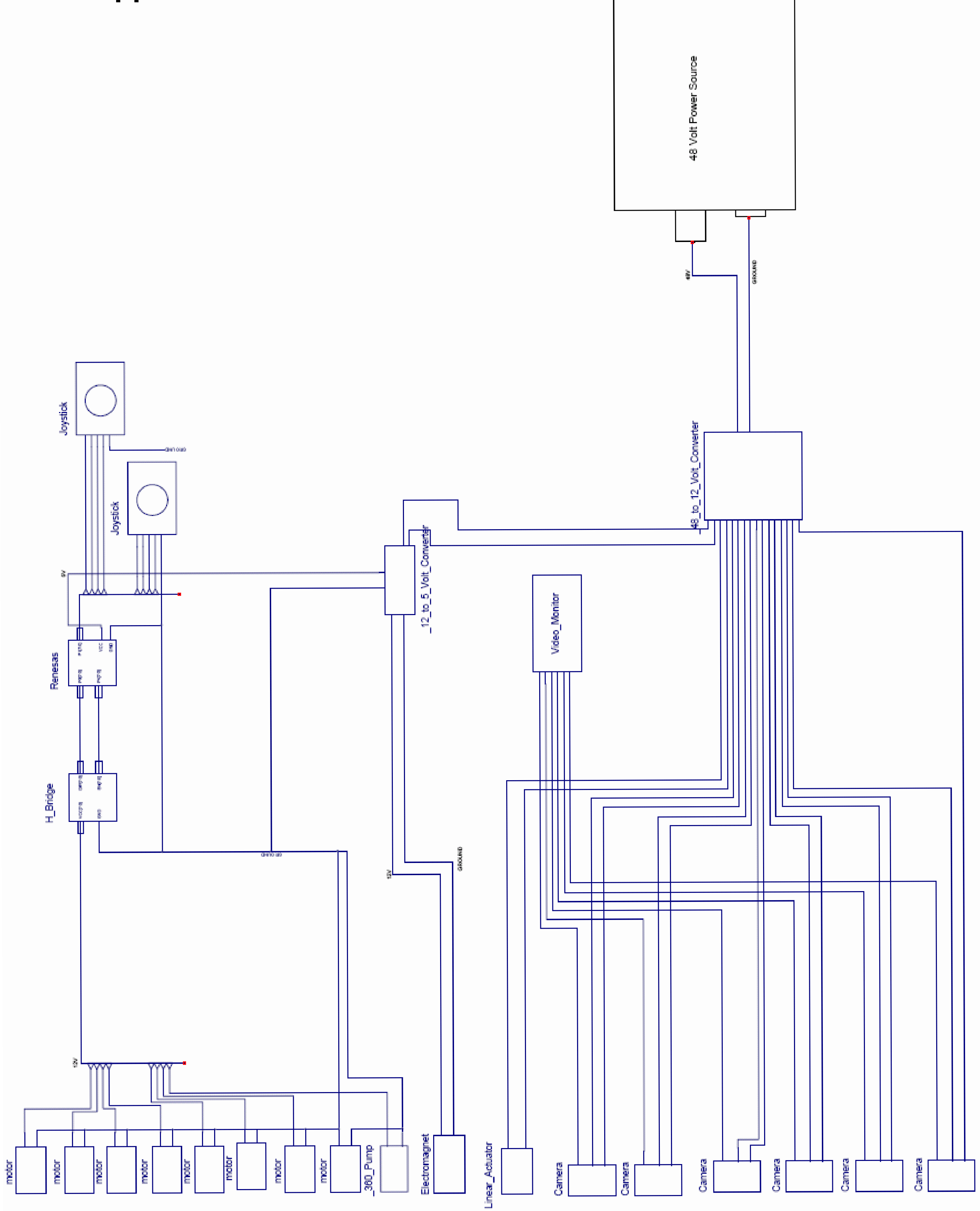
Sysco (Frame)
Kelly's Restaurant (Frame)
Jane Shipman (professional advice)
Anna Thomas (professional advice)
Donald Blackmon (professional advice)

Figure 25. Patterson and Zach at the HDR interview

A special thanks goes out to our parents and mentors for guidance during the competition, time input and the long haul up to Massachusetts.

CHARLOTTE AREA ROBOTICS

Appendix A- Electrical Schematic



Appendix B- Electrical Schematic for old tether