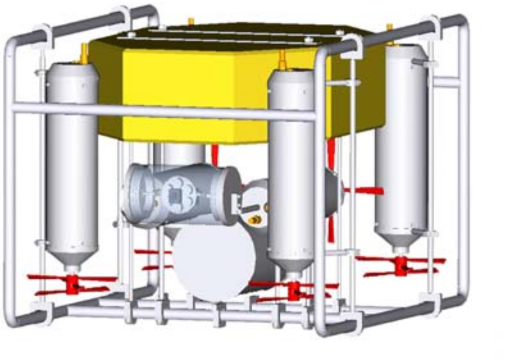
Lake Superior State University

Robot for Aquatic Development and Research
(Team RADAR)



Final Paper Submission for the Explorer Class 2004 MATE/MTS ROV Competition

University of California, Santa Barbara (UCSB)
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Abstract

Since 2002, the Marine Advanced Technology Education (MATE) Center and the Marine Technology Society (MTS) have worked together to offer a competitive summer event that provides high-school through university students an opportunity to compete with an underwater Remotely Operated Vehicle (ROV) that they have designed and built. This year's competition takes place at the University of California, Santa Barbara (UCSB). The competition focuses on completing an underwater mission as defined by MATE and MTS. The mission for this year involves a mock-up of a sunken U-boat on a reef. Each team is required to maneuver their ROV through the reef, locate the U-boat, perform measurements at the U-boat, retrieve a pinger, retrieve a towfish, measure the temperature of a cold spring, sample fluid from a leaking barrel, and recover the captain's bell. Teams are judged on their ability to complete and/or accurately measure each aspect of the mission within a fixed time period.

Team RADAR from Lake Superior State University (LSSU) has designed and developed an ROV and control system that will allow their vehicle to meet the design specifications set forth for this competition. This paper discusses the design of that vehicle and provides information on the solutions proposed to meet the challenges set forth by the MATE/MTS sponsors.

Introduction

In 2000 a group of engineering students at Lake Superior State University (LSSU) wanted to build an ROV. They began by reviewing the literature and found a book entitled "Build Your Own Underwater Robot", by Harry Bohm and Vickie Jensen [2]. A professor within the engineering department at LSSU saw the student's enthusiasm and decided to pursue the idea further by attending the 2001 MATE Summer Institute for ROV design. Upon his return to LSSU, he encouraged students to build a second ROV and enter it into the 2002 MATE ROV competition held in Cape Canaveral, Florida. The experience was very educational for both the students and the faculty who attended. Students returned to LSSU after the competition and began work on their third ROV, which was to have two purposes. Those purposes were to provide a platform for future research at LSSU and to use the ROV to promote the LSSU engineering program through such activities as the MATE/MTS ROV competition. That ROV was entered into the 2nd Annual MATE/MTS ROV Competition held at Massachusetts Institute of Technology and was awarded first place [3]. This year the ROV is returning to the competition with new motor driver electronics, a new control system, new sensors, new lights & cameras, and a small arm. All components are design to meet the challenges of the competition.

The ROV has been built and has undergone some testing, but the true test will come at the competition. This paper will provide details about the design of the LSSU ROV. Information on the design rationale, design challenges, final designs, troubleshooting & testing techniques, lessons learned, budget, and a conclusion with future improvements will be presented. Information on how ROVs are used to explore and understand national marine sanctuaries will also be provided.

What is an ROV

During the course of human exploration and innovation, many environments and activities have proven to be far too hostile or dangerous for direct human involvement. Such environments range from the crushing depths of the ocean, to the freezing vacuum of outer space. In places such as these, human innovation has led to the development of unmanned mobile machines, also known as Remotely Operated Vehicles (ROV's). ROV's interact with these environments, and through sensor feedback and complex control systems, allow the human operators to have a virtual presence or telepresence in a place where they could not normally or safely go. One very prevalent branch of ROV development is dedicated to underwater exploration; so much so that the term 'ROV' has now become synonymous with the phrase 'underwater ROV', and it is in that capacity that the term will be used for the remainder of this document. The development of an ROV is the focal point of the LSSU ROV research project. For a better understanding of the engineering issues related to the design of an underwater ROV, this section covers the basic components of an ROV and discusses how ROVs are used in marine sanctuaries.

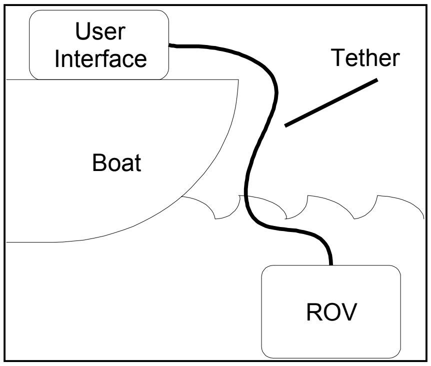


Figure 1: Basic ROV Components

General Overview of an ROV

A complete ROV system is comprised of three major components (Figure 1). A person (or user) controls the Remotely Operated Vehicle on the surface, either in a boat or on land. The user will operate a custom-built user interface that sends commands to the ROV and displays sensor feedback from the vehicle for the user. Because radio signals degrade rapidly underwater, and because the ROV's do not typically carry a power source of their own, control signals and power are sent to the vehicle through a specially constructed cable called a tether. The vehicle itself is comprised of several systems. In particular, the vehicle has motors and actuators that allow the vehicle to interact with its environment, as well as sensors that allow the user to monitor the operation of the ROV as it interacts with its surroundings. The ROV also carries electronic systems, which serve as an electronic link between the user interface electronics on the surface, and the ROV electronics for the motors and the sensors. The LSSU ROV has six motors for propulsion and two camera controlled by a user on the surface. A joystick is the main device used to control the ROV.

Applications of ROVs

ROVs have found great utility in exploring and understanding our national marine sanctuaries. There are currently 13 marine sanctuaries in the United States covering over 18,000 square miles that protect our living resources (animals and plants) and historical shipwrecks. These sanctuaries exist in both fresh and salt water and provide great opportunities for exploration and study [4]. Unfortunately, as more people want to observe these habitats, they create more disturbances to the sites. This is where ROVs can be used. Using ROVs, many people can view and experience the treasures under the sea with minimal disturbance. The ROV can gather data through a wide variety of sensors or through video imaging. Furthermore, the ROV can go deeper and into extremely hostile environments where humans cannot travel. Using ROVs, new animal and plant life has been discovered, new shipwrecks have been found and new areas of the underwater world are being examined every day [5].

Maybe even more important, is the ability of the ROV to bring the underwater into the classroom and laboratory. Live video feed or even live data can be transmitted directly into classroom around the world or into research facilities. The Thunder Bay National Marine Sanctuary and Underwater Preserve uses ROV to study hundreds of shipwreck ranging from 20-200 feet underwater. The sanctuary works with the National Oceanic and Atmospheric Administration NOAA and other sites to broadcast high quality video around the United States [5].

The Mystic Aquarium Institute for Exploration hopes to bring information from all the national sanctuaries together and provide this information to the general public. They would provide live video information from all the sanctuaries via advanced ROVs and the Internet. Their goal is to "help each visitor realize that your actions – and those of every other person – affect our oceans and the life in the Marine Sanctuaries, and that these natural resources must be preserved for future generations"[6]. They have already started with the largest sanctuary (the Monterey Bay sanctuary in California) and plan to add others in the near future.

ROVs in the future will probably work together to monitor drinking water quality, provide secure shipping lanes, and even protect our coastlines. The field is only in its infancy and the types of applications will be extremely broad. It will be interesting to see what the future holds for ROVs.

The LSSU ROV

The LSSU ROV resembles what is typically referred to as a workhorse ROV and is shown in Figure 2. It is fairly large and weighs about 136kg. A workhorse style ROV is a tethered vehicle, which is generally used for heavy load applications. These ROVs are designed to be capable of handling large payloads, while also being able to be used for exploration. Using this type of frame allows for good expansion in future design modifications.

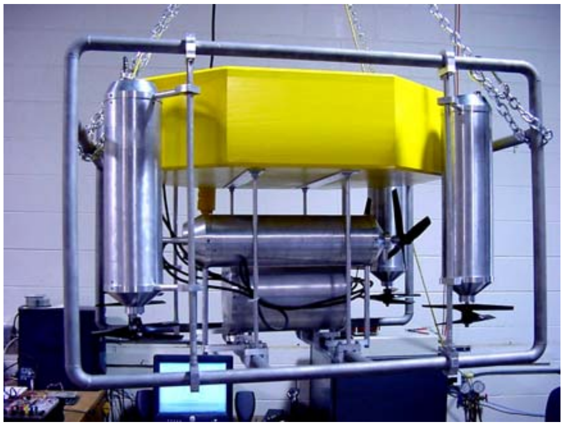


Figure 2: Completed LSSU ROV

The ROV has six motors for propulsion. Two motors all for maneuvering forward and back and four motors for moving up and down. It operates from a single 300 volt DC power supply that delivers 4 amps of current for a total power of 1.2kW. The 300 volts is transformed to 48 volts and sent to the ROV via the tether. A joystick is used to control the ROV as it moves through the water. A user has access to a wide variety of sensory information including two camera views, motor speed indicators, motor temperatures, water temperature, leak detection, depth, and power utilization. The basic ROV was designed and built last year. Several modifications have been made to the system and several sensors were added for the competition. The following section will describe the changes to the ROV and the designs implemented to meet the competition requirements.

Design Specifications and Rationale:

Several specifications were noted in the "Competition Challenges and Design & Building Specifications" [9]. Generally, each specification required an engineering design & build solution. LSSU's Team RADAR has designed specialized equipment for this year's MATE ROV competition. Some of the pieces of equipment will be used to solve more than one task.

In general, this year's competition involves using an ROV to survey and retrieve artifacts from a sunken U-boat. The U-boat lies on a reef in shallow water. The following is a description of each task that must be performed at the U-boat site, and the solution chosen for that task.

Periscope Depth Measurement

A periscope located on the U-boat extends a length of 30-60 centimeters from the U-boat. The periscope is vertical and at right angles to the U-boat. The periscope will have a mark on it. Each team is to devise a method of measuring the depth of the periscope at the level of the mark. The depth measurement should be accurate within 5cm.

For this task LSSU's Team RADAR has designed a 'KISS Compliant' depth measurement system. The system consists of a common reel tape measure that has been attached to an electric motor and a weight, and then mounted to the vehicle as shown in Figure 3. The tape measure has been positioned in such a way that the measurement can be easily read by the on board camera as seen in Figure 4.

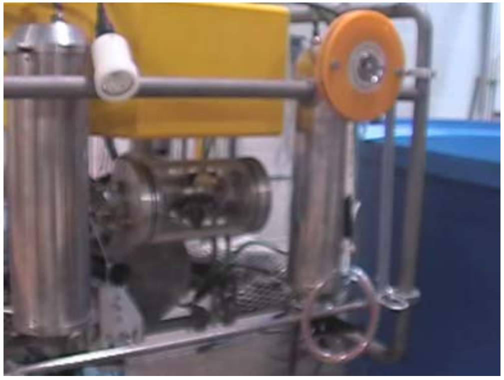


Figure 3: ROV and Tape Measure

Figure 4: ROV Camera Showing Tape Measure Deployment (left side)

Team RADAR has developed a two-step procedure for determining the depth of the periscope marking. First, the ROV will come up to the point where the periscope is positioned. It will line itself up so that the mark is directly in front of the camera. It will then drop the weighted end of the measuring tape to the bottom of the pool. A team member will record the measurement in a notebook. The ROV will then rise to the surface of the pool and perform a second depth measurement. The difference between these two measurements, plus the distance from the camera on the ROV to the top of the ROV will be the depth of the marking on the periscope.

Cold Spring Temperature Measurement

A cold spring will be located inside a cavern somewhere on the reef. The ROV must carry or extend a temperature sensor into the cold spring and measure the temperature. This temperature must be displayed at the user interface.

To solve this problem Team RADAR plans to use a thermocouple mounted on their manipulator (which will be described in more detail later) as shown in Figure 5. The thermocouple is connected to a thermocouple signal conditioner. The signal conditioner allows a microcontroller on the ROV to read the thermocouple output and send the information to the control computer on the surface, where the user interface program converts the encoded data into a readout (in degrees) for the operator to view. A block Diagram of the system is shown below in Figure 6.

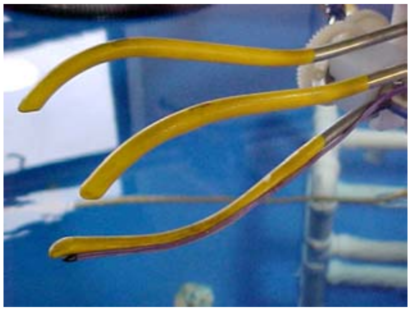


Figure 5: Thermocouple Mounted on Gripper

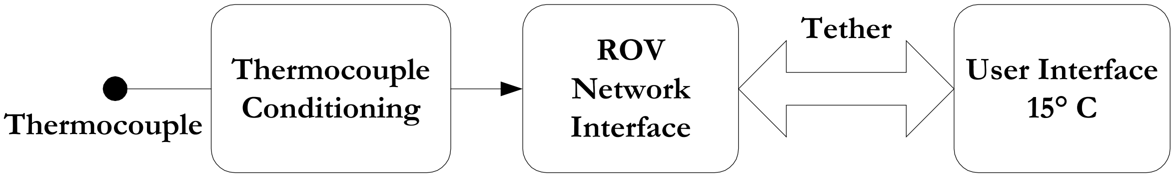


Figure 6: Thermocouple System

Leaking Barrel Sample

When the U-boat sank, it contained some barrels of unknown origin. These barrels are now leaking material into the environment and therefore pose a potential environmental problem. Our task is to locate one of these barrels and retrieve a 500ml sample from the barrel. The sample must be retrieved uncontaminated and returned to the surface for later analysis.

To address this specification, Team RADAR has designed a dual pump system with an I.V. bag reservoir. A block diagram of the system is shown in Figure 7.

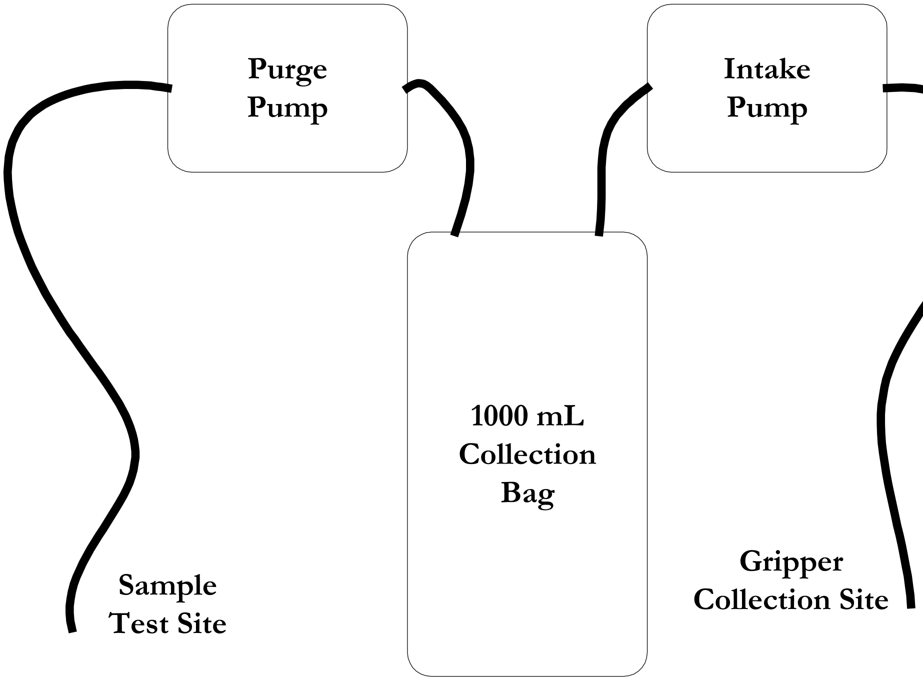


Figure 7: Leaking Barrel Sample Collection System

The ROV gripper will place the intake pump hose into the barrel and then actuate the intake pump. The system is design to pump 500 ml of fluid from the barrel. Once at the surface, the purge pump will empty the collection bag for analysis. The two-pump system allows the contents of the I.V. bag to be purged in the event of a bad sample. A collecting hose will extend from the intake pump to the end of the gripper, which will allow the hose to be placed in the end of the leaky barrel. The I.V. bag has a 1000ml capacity, allowing for over-sampling.

Captain's Bell Recovery

The commander of the U-boat was issued a special bell for his years of service. This bell is now lost somewhere on the reef and must be recovered. Our objective is to locate this bell, retrieve it, and bring it to the surface.

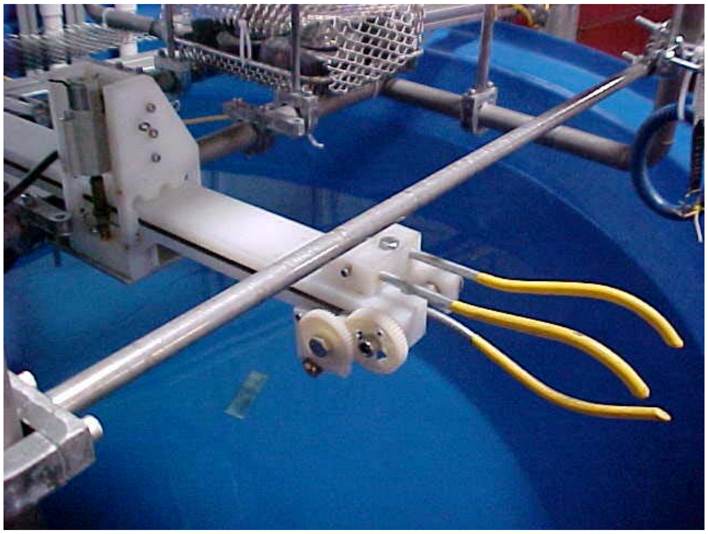


Figure 8: Custom Designed Gripper / Manipulator

To solve this problem, Team RADAR plans to use the ROV's camera system to recover the bell. The team plans to use a manipulator that they have custom designed for this competition. The custom gripper, shown in Figure 8, is powered by two geared DC motors, and has a total reach of 0.3 meters. The three fingered gripper has been curved and coated in 'Grip Dip' to allow it to firmly grip both the captain's bell and the pinger.

Towfish Recovery

Earlier surveys of the wreck site used a towfish. The towfish was expensive and was accidentally lost as it became entangled on the reef. Our objective is to locate this towfish, retrieve it, and bring it to the surface.

To find the lost towfish, Team RADAR plans to use the ROV's on-board cameras, and once the ROV has located the towfish, they will use a carabeaner fixture, held in the ROV's gripper, to grasp the eyelet on the towfish. There will be a rope attached to the fixture leading to the surface so that after the towfish has been grabbed a team member can pull it to the surface. The carabeaner fixture is shown in Figures 9a and 9b.

Figure 9a: Towfish Recovery Bracket

Figure 9b: Towfish Recovery Bracket in Gripper

U-Boat Measurement

Standard techniques for mapping historical wreck sites involve taking measurements of the wreck and its surrounding. Since we are investigating the wreckage of this U-boat, we are required to measure the length of the U-boat and record the data. This data will help to ensure the U-boat origin, age, etc. The U-boat has been marked with two white lines. Our task is to measure the distance between these two marks.

To measure the length of the U-Boat, Team RADAR plans to use the motorized tape measure. Along with having a weight on the end of the tape measure, the team planned to add a ring that can be dropped around the peg at one end of the U-Boat. Using the difference between the first measurement and a second measurement taken after backing all the way up, the team can determine the correct length of the U-Boat.

Pinger Recovery

On the original survey, a pinger was thrown overboard to help locate the wreck in the future. Our objective is to locate this pinger, retrieve it, and bring it to the surface. To make the test a little more challenging, several fake pingers have also been placed on the reef. Only one pinger will be functioning. We must locate and recover the correct pinger.

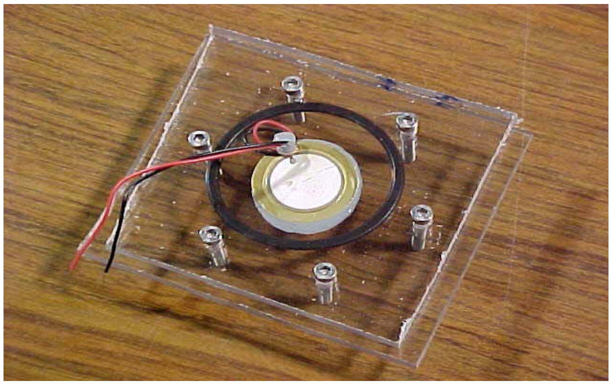


Figure 10: Acoustic Sensor

To locate the pinger, Team RADAR has designed an underwater microphone that is not only waterproof, but that appears to function well outside of the audible range, as well as within the whole audible range. The team has custom designed and manufactured a 2.5 watt audio amplifier which will enable the signal from the sensor to be transmitted up the tether to a set of headphones on the surface. The sensor will be placed in a tube, to enable it to be directional. An operator on the surface can listen to the feedback from the sensor and, by aiming the ROV, can determine which of the pingers is active. Once the active pinger is determined, the ROV's gripper will be used to recover the active pinger. The acoustic sensor is made from a Piezoelectric crystal, purchased at Radio Shack, and then sandwiched between two sheets of Plexiglas, using an o-ring for waterproofing (see Figure 10). The amplifier uses an LM380 amplifier chip, as it's primary building block, and was made entirely here at Lake Superior State University. The Amplifier circuit is shown below in Figure 11 as it is mounted in the main electronics housing.

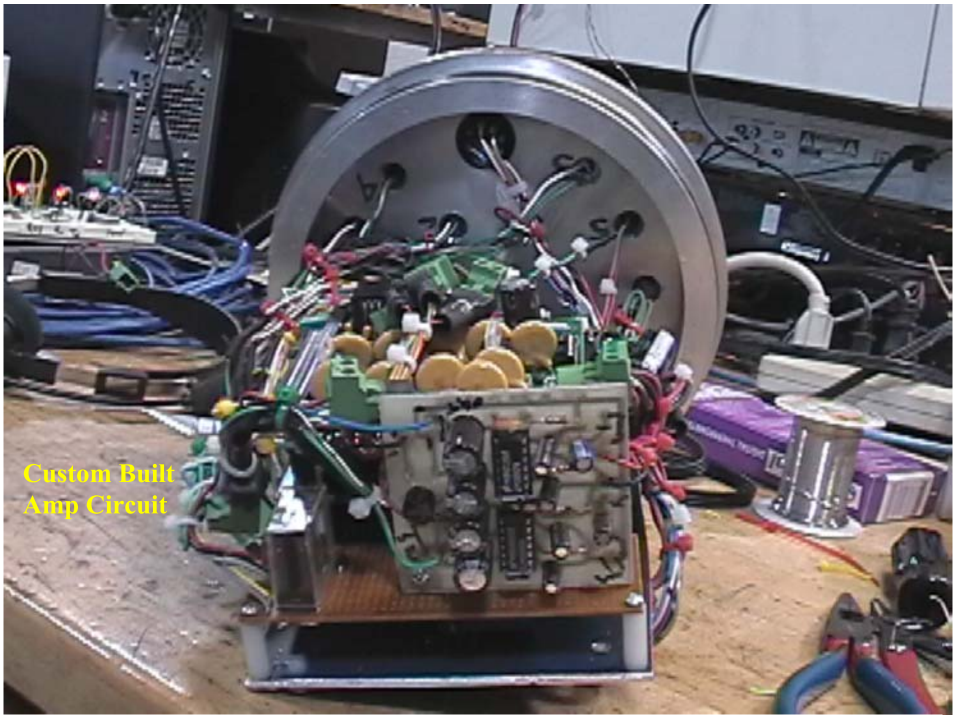


Figure 11: Custom Amplifier Circuit installed in Main Electronics Housing

Design Challenges

Some of the biggest challenges in this project were the varied nature of the tasks to be accomplished. We tried to design as many pieces of equipment as possible to be able to be applied to as many tasks as possible. We thought that making an underwater audio sensor would be extremely difficult, but that proved to be fairly simple once we started doing research. A large factor in all of our designs was also designing for possible failures. We tried to design every component so that it would be easy to fix even after a total failure, or so that it would still function if everything else around it failed. We also tried to make every part of the design as redundant and rugged as possible. While trying to keep these ideals in mind was difficult at times, the team feels that the ROV as a whole came out much the better because of it, and that it is now a versatile, and dynamic ROV platform.

Final Designs

The fully assembled ROV can be seen in Figure 12. The figure shows the four vertical thrusters that allow for up and down movement. It also shows the three horizontal housings. The two smaller horizontal housings are motor housings, which allow the ROV to turn and move in the forward and reverse direction. The large diameter housing is the main electronics housing. It houses the main microcontroller and the sensors not associated with the motors. There is also a clear acrylic housing mounted to the front of the main electronics housing. This clear housing is the main camera housing. The yellow octagon on the top of the ROV is the foam floatation. This allows the ROV to remain neutrally buoyant in the water. Lastly, there is a stainless steel crash frame, which encapsulates the ROV. This frame was designed using stainless steel so that it can withstand any possible collisions in the water.


Figure 12: Completed LSSU ROV

The ability to control the ROV was a very important consideration in the design. It was decided that the user must be able to easily control the ROV from the surface using a joystick. The joystick commands must be recorded, put into a transmittable package and then sent to the vehicle.

Troubleshooting & Testing Techniques:

The team encountered several extremely frustrating problems throughout the course of the year, both electrical and mechanical. Figure 13 shows the newly completed electronics package in a test stand, a place where it spent several weeks as the team tried to track down electrical noise issues and refine the motor control software. One of the greatest benefits to the team during the troubleshooting phase was the ability to write custom testing software. Figure 14 shows a screen shot of a program that was custom written by a Team RADAR member to allow another team member to run diagnostics on the MATE motor control board.

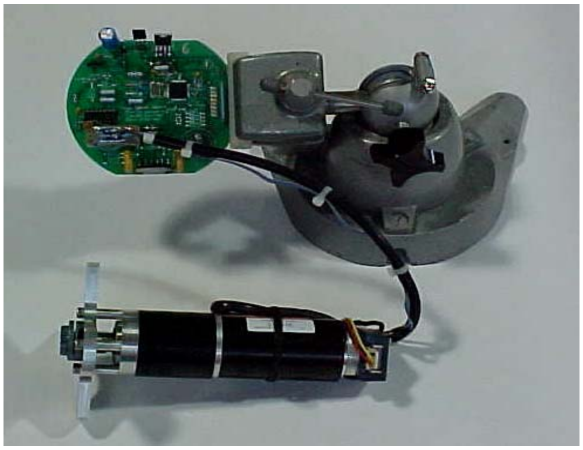


Figure 13: Motor Control Electronics on Test Stand

Having custom control software at our disposal allowed the team to isolate problems quickly, and sped the development process along a great deal. Custom software was written that allowed each individual component of the ROV to be tested individually, which led to very few problems as the individual subsystems of the ROV were assembled into the final robot.

The biggest troubleshooting skill that the team learned this year was fault isolation, the skill of determining where, in a large, complex system, such as an ROV, a problem is occurring. Fault isolation is usually accomplished by a 'divide and conquer' strategy, when you are having a problem with an electrical short for instance, you can start by unplugging the motor tubes, one by one, and when the short stops, you have found the tube.

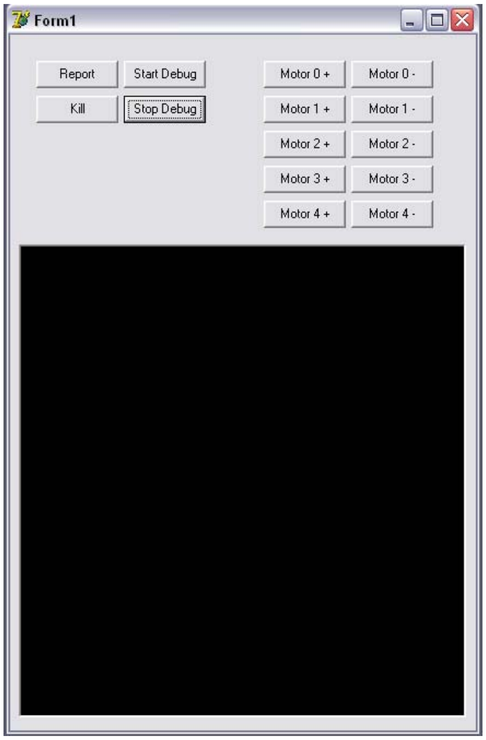


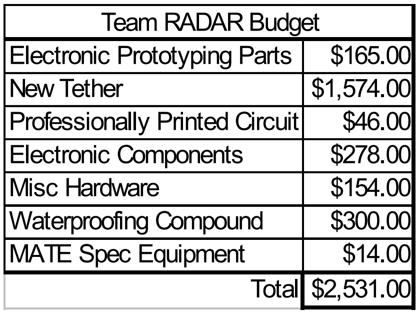
Figure 14: Custom Testing Software

Lessons Learned:

The most important lesson learned throughout the completion of this project is task management. This was a very large project to complete. Each member had to keep up to date with the project accomplishments and if a member started to waiver it was imperative that another member step in and point them in the right direction. If the entire team does not stay on task then the project timeline keeps being pushed back. Maintaining documentation was also very helpful when it came to creating assembly, testing, and other documentation. Lastly, if there was one thing that could be reiterated it would be to finalize the system design before purchasing components. If the design changes and the parts have already been ordered, then the budget in sacrificed.

Budget:

Team RADAR was alotted a budget of $3000 for the improvements that it planned to make to the ROV during the course of this school year. Through creativity and hard work, the team has completed a major set of modifications and managed to come out well under the alotted budget. The largest single item was the new tether that the team purchased from Falmat Cable. The other largest item, in total, was the electronics system upgrade. A Large deal of the electronics cost was offset by ordering parts through sample distributions, as they only required small quantities.
The Team RADAR Budget for 2003-2004 is shown at right in Table 1.



Team RADAR Budget	
Electronic Prototyping Parts	$165.00
New Tether	$1,574.00
Professionally Printed Circuit	$46.00
Electronic Components	$278.00
Misc Hardware	$154.00
Waterproofing Compound	$300.00
MATE Spec Equipment	$14.00
Total	$2,531.00

Table 0 Team RADAR Budget for 2003-2004

Conclusion & Future Improvements:

Working on the ROV project was a demanding yet rewarding experience. It provided a wealth of real-world knowledge for all the students and challenged everyone. As we worked on the project, we sometimes found better ways to accomplish a task, but due to budget or time constraints, we couldn't implement our idea. Many of the ideas from last year's team were implemented or improved upon. We added a real tether, modified the camera for better pan and tilt, improved the motor control systems, and added acoustic capabilities. Some of our ideas for future work would include dynamic modeling of the ROV for enhanced control, addition of a mechanical arm, and addition of an automated location system.

The ROV is actually quite close to becoming an AUV or autonomous underwater vehicle. Future work may entail the creation of a new AUV for LSSU. Our only real concern is on board power, but we feel there are several options that can be pursued to accomplish this task.

Overall, Team RADAR is pleased with the status of it's ROV and hopes that future LSSU students will continue to work on the project and improve on its design. The system is versatile, well documented, and should serve as a good platform for future ROV research at LSSU.

Acknowledgments:

Team RADAR would like to thank the MATE/MTS ROV committee for hosting and funding the third annual ROV competition along with UCSB for providing a venue to hold the event. SeaCon & Brantner donated the main bulkhead connector used to mate the ROV and the tether. Maxon Motor was very helpful and allowed for an educational discount for the six motors used to propel the vehicle. Microchip Technology provided sample PIC18F452 microcontrollers for the motor controllers. The team would like to acknowledge the vast amount of assistance the members of EG260 (Under Graduate Research Methods) have put into the ROV project. Lastly, Team RADAR would like to thank LSSU for their funding and support for the duration of this project (especially Professor Morrie Walworth).

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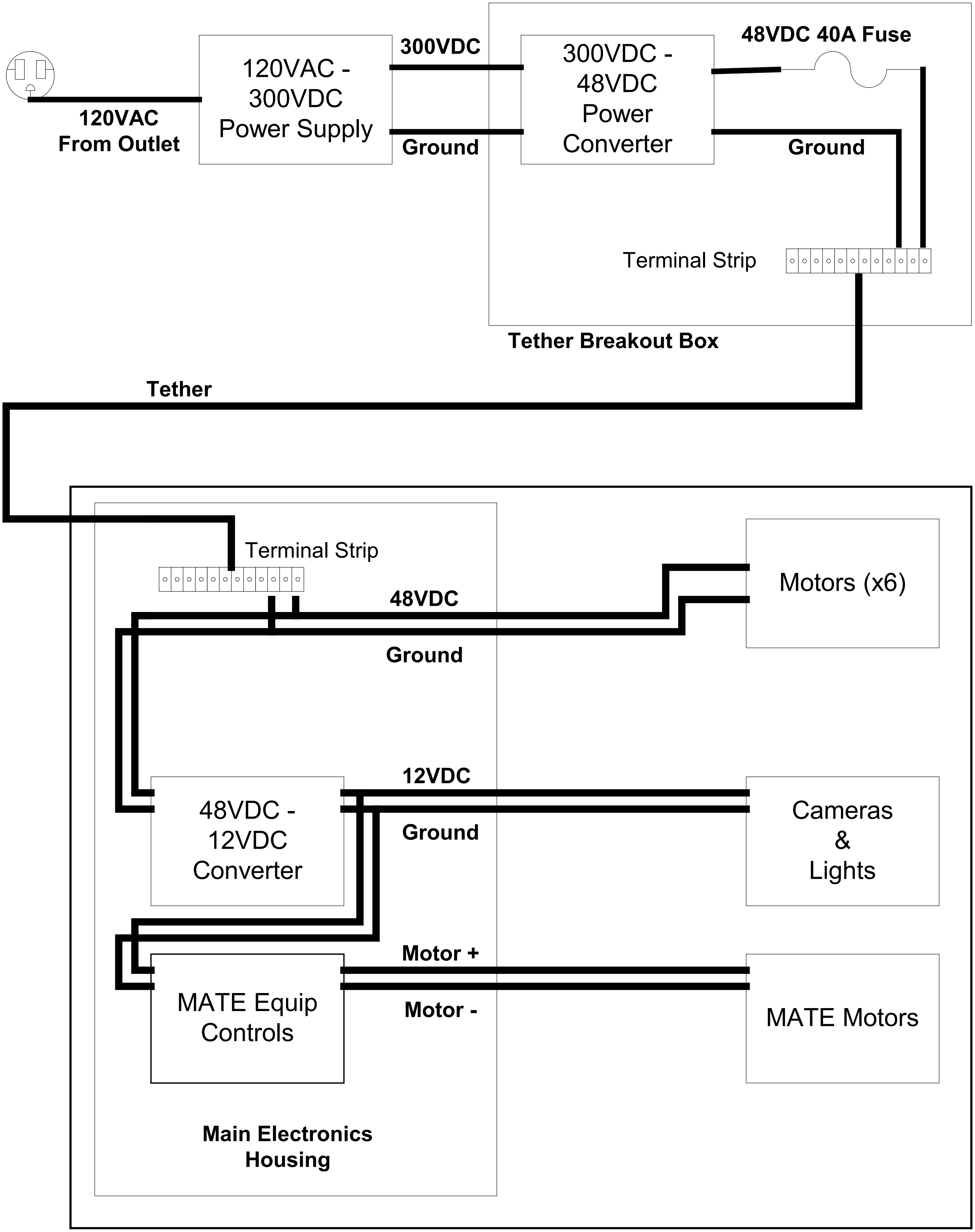

LSSU ROV Power
Distribution Diagram