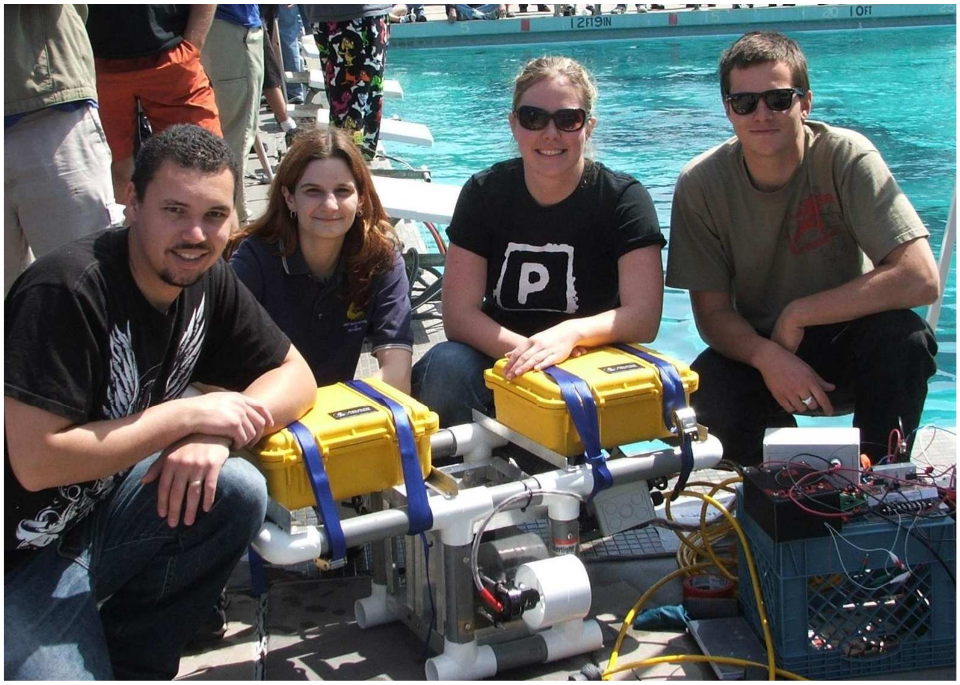
University of California, Santa Cruz
Jack Baskin School of Engineering

ROV *Sea-Slug*



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ABSTRACT:

The 2008 MATE ROV competition will be the first time a team from the University of California, Santa Cruz (UCSC) has competed. Our group came together in the Computer and Electrical Engineering senior design class with a common interest in building an underwater Remotely Operated Vehicle (ROV). We saw the competition as a perfect way to focus our project and define its purpose. To ensure the success of our project we simplified components where possible. Minimal funding left the majority of the project to be paid for out of pocket, so we also took donations where possible to cut down on costs. This meant having a flexible design so we could adapt to available materials. We used parts that were already waterproof, such as bilge pump motors in our thrusters and Pelican cases for floatation. We also kept all of our electrical circuits, except the temperature sensor, in a control box on the surface to eliminate the possibility of leaks.

We began our design planning in February 2008. Now four months later we are very pleased to present the first UCSC ROV, *Sea-Slug*, at the 2008 MATE Competition.

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ROV Sea-Slug photographs:

Figure 1: ROV *Sea-Slug* (Top View)

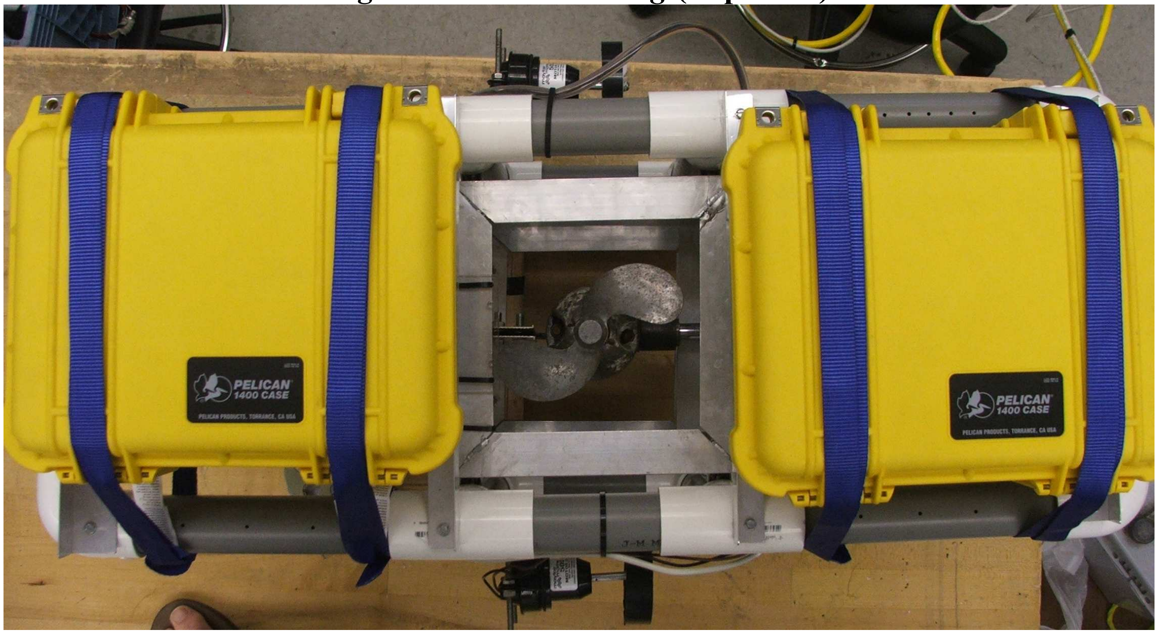


Figure 2: ROV *Sea-Slug* (Front View)

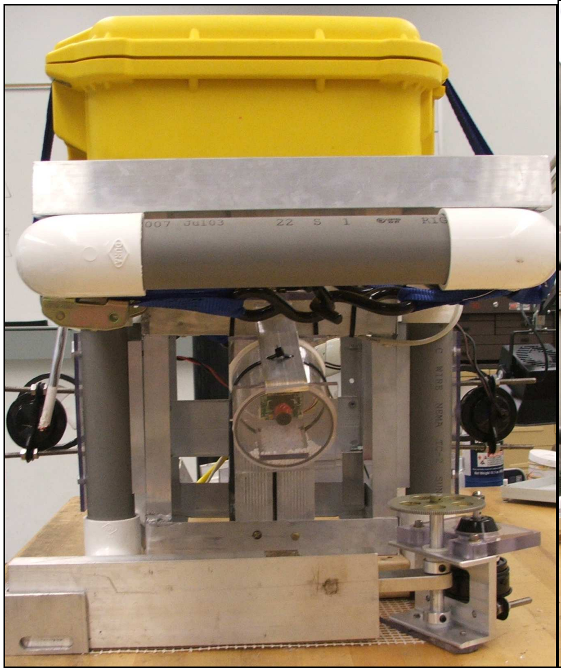


Figure 3: ROV *Sea-Slug* (Back View)

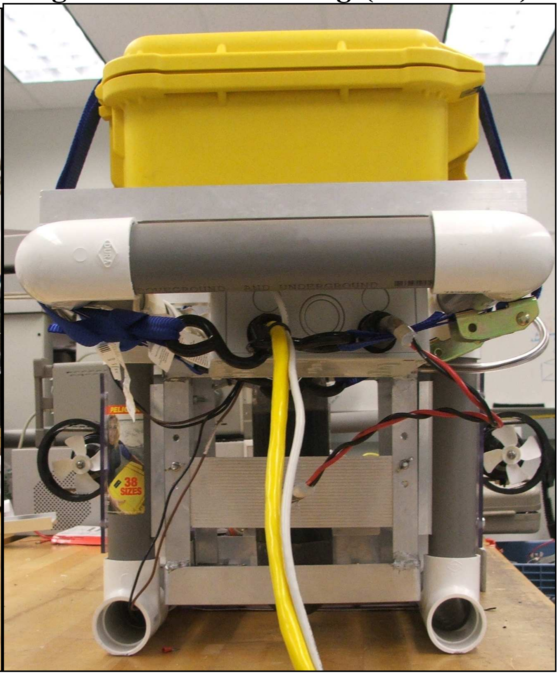


Figure 4: ROV *Sea-Slug*

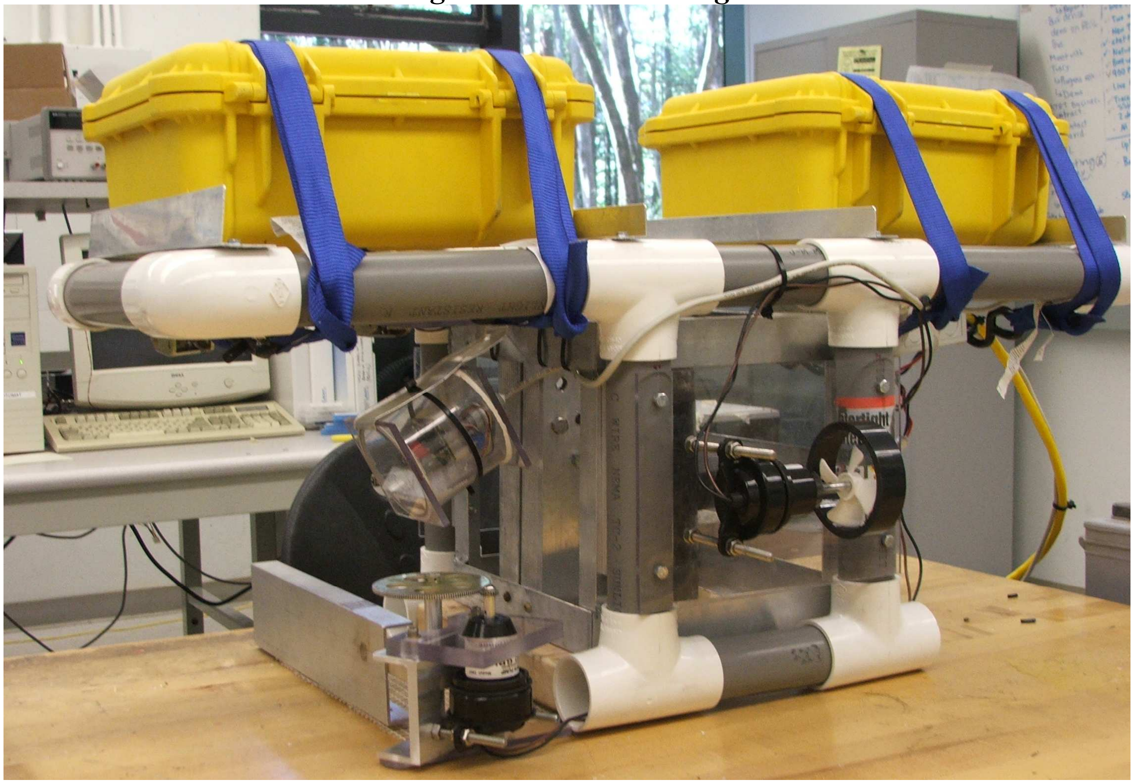


Figure 5: ROV *Sea-Slug*

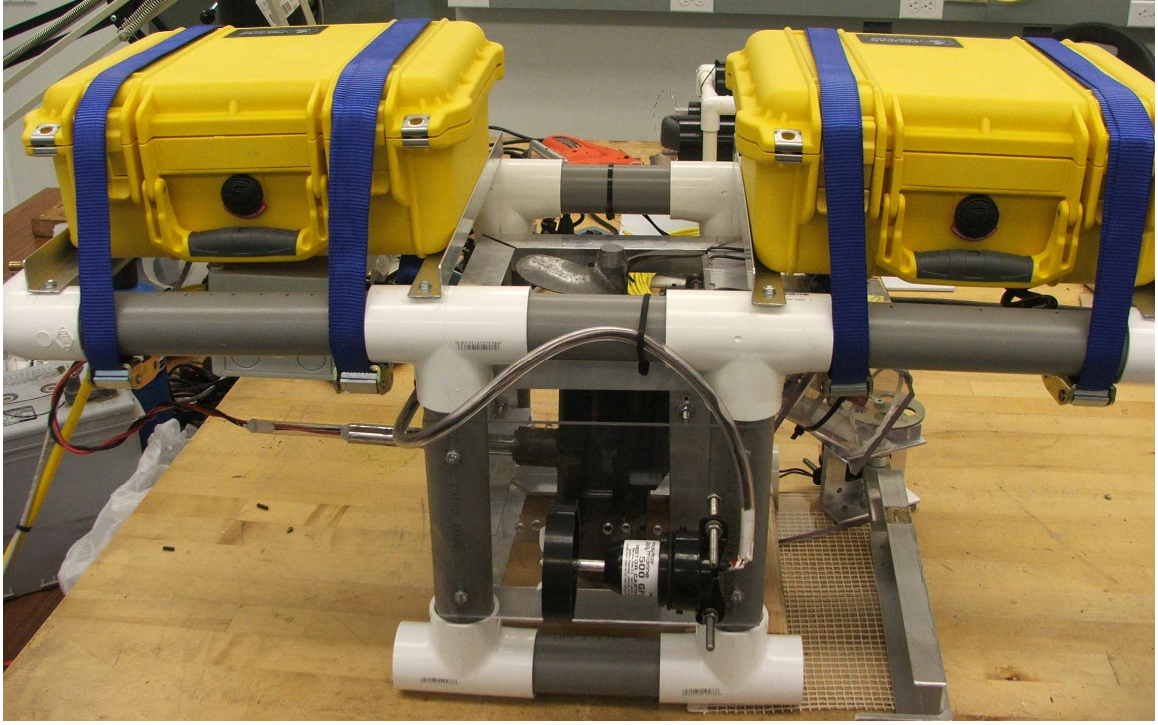
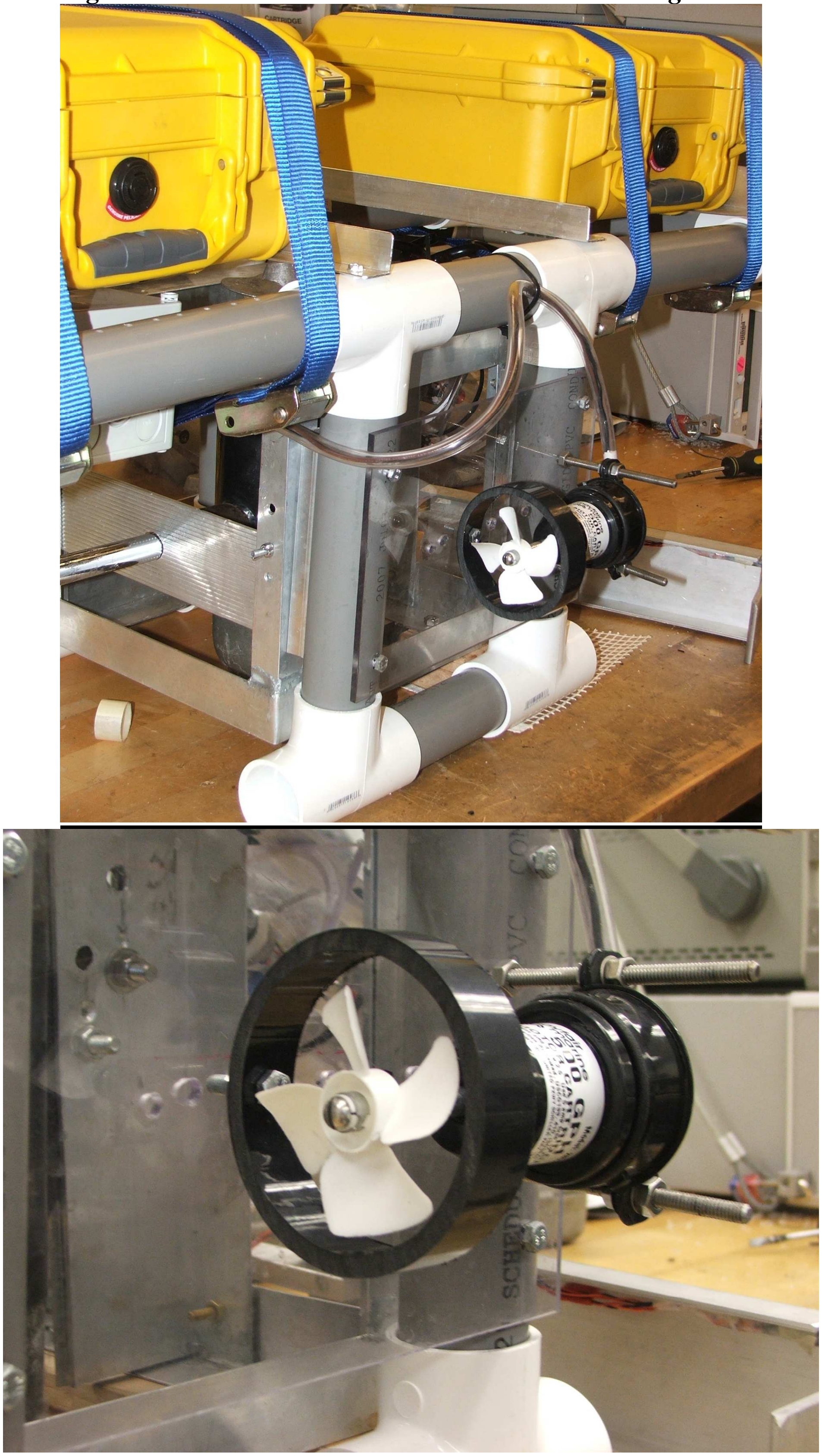


Figure 6a&b: Side thruster with shroud on *Sea-Slug* frame

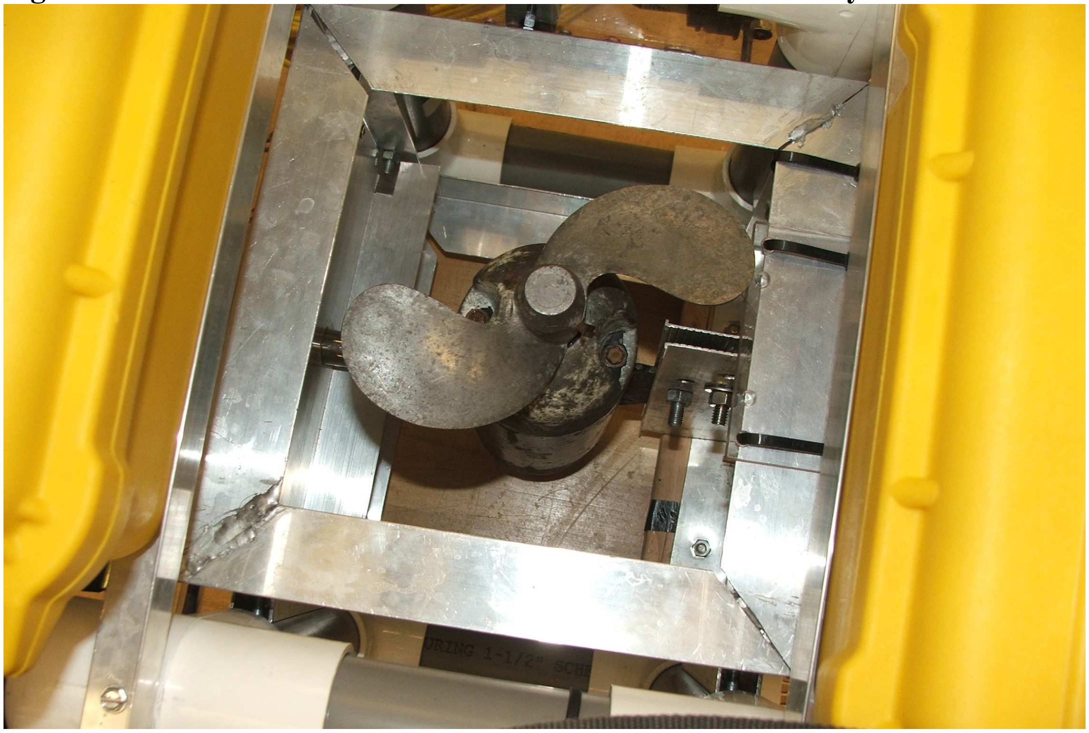


Design Rationale:

We began our design with simplicity in mind since none of our team members have a background in Mechanical Engineering and we had to start from scratch. From our research of the vehicles at the Monterey Bay Aquarium Research Institute (MBARI), we learned a few basic principles which guided our design. First, to maximize stability, we wanted to have the buoyancy on the top and most of the weight at the bottom and center of the craft. We decided three bidirectional thrusters for movement would be sufficient; one for vertical motion and one on either side for horizontal maneuvering. Since this motor arrangement does not give us control of roll or pitch of the ROV, the buoyancy and weight distribution became critical. Also, water and electronics usually do not mix, so we knew waterproofing was going to be an issue. We decided to utilize products that were already waterproof such as the bilge pump motors used in our thrusters. We made our own water tight seals whenever necessary using a combination of cable glands, pvc tubing, marine adhesive, and epoxy.

With these design theories in mind, we implemented them with the materials we had available. One of our professors offered us a used 12 volt trolling motor and we decided to use it for our vertical thruster. With its large size and 4.54kg mass, we knew it would have to be centered in the ROV if we were to maintain the balance of the craft. We then designed the frame, shown in Figure 7, to be made of welded aluminum and bolted to the PVC piping which holds the rest of the components

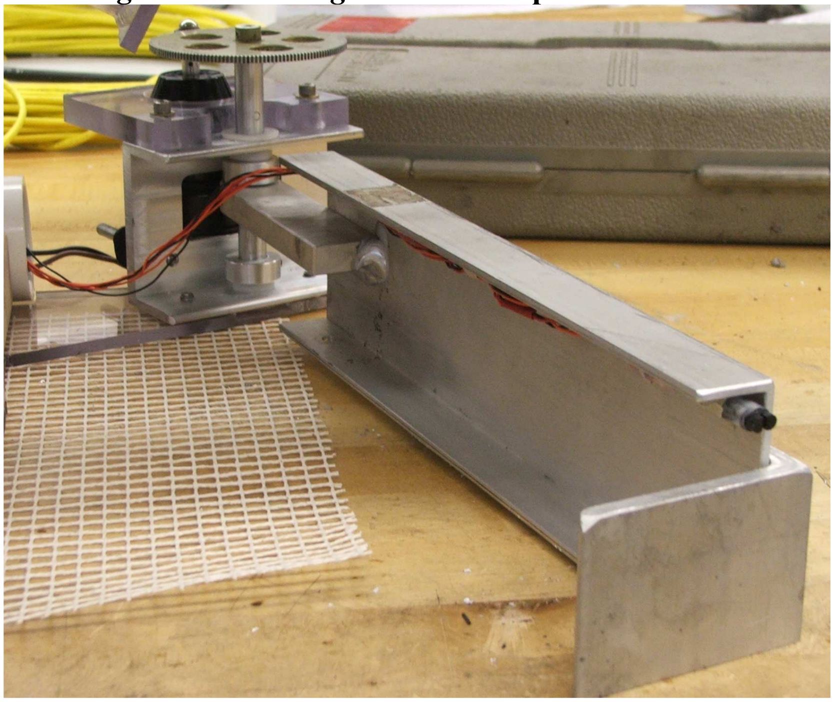
Figure 7: Aluminum frame for vertical thruster surrounded by floatation cases.



Our next concern was with the ballasting. A solid floatation device was needed to offset the mass of the trolling motor and ensure that the ROV will return to the surface should the electronics fail. We decided to use Pelican cases to provide the positive buoyancy we needed. Pelican cases are pressurized, waterproof cases that come in a variety of sizes and buoyancy ratings. Pelican kindly donated two cases for us to use on the front and back of the top of our ROV as floatation devices.

The armature was made to be as simple as possible, while keeping in mind that we wanted the majority of the weight of the ROV to be centered. We finalized a design that acts as a sweeping arm with one range of motion for collecting samples into a net attached to the bottom of the ROV. This motion is achieved by one motor, also a bilge pump motor, and a system of two gears with a ration of 6.5:1. The gears add the extra torque to the motor to give the arm enough strength to move a 0.907kg dive weight onto the netting of the craft. To keep the weights in position while moving them with the arm, we added a corner piece to the end of the arm, shown in Figure 8 below. The arm, motor, and gear supports were made with aluminum and metal scraps from the Machine Shop at UCSC by one of our team members.

Figure 8: *Sea-Slug* arm and temperature sensor



For the temperature mission task we wanted to have something that would extend from the ROV, like the arm, so we could control its position separately from the thrusters. This would allow us to avoid complex maneuvering to keep the vehicle steady while we wait for an accurate temperature reading. Since we already have this control capability with the arm, we mounted the sensor on its far end and ran the wires along the top of the arm. In figure 8 above the sensor is shown at the end of the arm.

Challenges:

The main challenge our team faced relates to team dynamics. In particular we faced issues regarding team member inclusion, division of labor, and communication. In order to overcome these challenges, we decided to start with a clean slate, restructure the group, and to make specific commitments to each other; all of which manifested into a new team charter.

As part of a two quarter long senior design class at UCSC, none of us had ever worked on an engineering team for an extended period of time. Many of the problems in our team manifested in the second quarter, and were not confronted and dealt with until mid way through that quarter.

Initially we thought we would not need a team leader and we could all equally lead ourselves and the group. We were all excited about this project yet naive of what could happen to us as a team. Communication between members became a core problem, and caused friction, gridlock and reduced the quality of our discussions. Poor communication within the group began to affect the overall progress of our work. Recognizing that team functionality was suffering was an essential step in overcoming these issues. To remedy this problem, we had a team meeting to sort through our issues. The class TA was brought in as a mediator to ensure fairness during the course of our talks. In the end, we became more aware of each other's needs and found a middle ground.

We agreed to be more inclusive of others, have a positive outlook, respect each other's needs, and to work on better communication. Also, we decided to restructure the group which involved changing the group leader and each of us taking on additional responsibilities. This transition caused us to lose a few days work to refocus on our team. However, this time was very useful and as a result the communication in our group has improved greatly and we are more comfortable working together.

This problem was something that none of us had anticipated. We all recognized that it was more than just keeping our issues to ourselves to get through the project. We all committed ourselves to deal with the complications and in the end it helped our work and the final result of our ROV.

Troubleshooting:

Problems will inevitably arise when working on a project of this size, and learning to pinpoint problems in a complex system is an important skill we all had to learn. Troubleshooting usually begins with the 'big picture' view: make sure nothing is missing, double-check the battery connections, look for loose wires, and check connectivity with a multimeter. Next, we use the voltmeter to check the voltage of the battery and the power lines going to all of the devices in question. If all circuits are powered properly, the digital signals are checked with the voltmeter to ensure they are within their proper operating range. Usually, if an inverter or a voltage regulator isn't working properly, the problem will be localized at this step and can either be rewired or the device will be replaced.

Once these basics have been covered it may be time to use an ammeter, oscilloscope or signal generator if the problem has not yet been found. The ammeter is connected in series with a device, such as a motor, to measure the current through that component. Usually the ammeter is used if there is concern that a device is drawing too much current or is not being supplied with enough current. The oscilloscope is used to measure time varying voltages and is very useful in observing and measuring transients and digital signals, such as pulse width modulation (PWM). Finally, the function generator can be used to drive a motor with a square-wave signal of given amplitude, frequency, and duty cycle to test its functionality with a PWM signal. This way, we can test a range of PWM signals without the trouble of programming the microcontroller repeatedly.

Lesson Learned:

One lesson we learned was how to be a team quickly. We started out not knowing much about each other and quickly earned to work with each other's strengths and weaknesses. Everyone has an opinion and they deserve to be heard and considered. We are the most productive and creative when we have group discussions and brainstorm. Everyone throws out ideas and we talk about all the possibilities. We found that this is the quickest way to get the best idea for the project to move forward.

We also experienced the importance of making an executive decision and sticking with it. There were times when a week's worth of work ended up not being right for the project. Recognizing that the work done was not a complete waste of time and effort even though it was not used in our end product can be very frustrating. You have to see the big picture and remember that time and money are the biggest factors when working on a team and sacrifices need to be made accordingly to insure the success of the project.

Spending lots of time debugging a problem that ends up being simple will always be frustrating.

Another lesson our team learned was how much work goes into revision. What we originally saw as the engineering design process was a linear progression with time. After experiencing how many times we needed to take two steps back to get one step forward, we found that many project components create a circular dependency on each other, making the redesign process very important.

Future Improvements:

The thrusters used on *Sea-Slug*, which is 22.7kg on land, are currently 500gph bilge pump cartridge motors, tested to have a torque of 0.54Nm each. The props are small for the motor size and lack the bidirectional efficiency our design calls for. To improve the efficiency, we added a small shroud around the prop to direct the flow of water, but the performance of the thrusters still leaves a lot to be desired. We would like to get bidirectional propellers that are 10.16cm wide instead of 5.08cm. The bilge pump motors come in larger GPH ratings, and we plan on installing 750gph motors to add force to the forward and backward movement of the ROV.

Research Project:

The Monterey Bay Aquarium Research Institute began their research of the Sea Cliff hydrothermal field, northern Gorda Ridge in 1988. The Gorda Ridge is speculated to be "an 'older' hydrothermal field, as it occurs on crust that the spreading rate would predict to be ~100,000 years old" (www.mbari.org). The chemically-rich waters emanating from the vents are heated by a magma chamber and come in contact with cold seawater. This causes minerals to precipitate to form the black "smoke" and build chimneys (www.mbari.org).

MBARI returned to the Gorda Ridge in 2002 to collected compositional data of fluids from the site. Their results are outlined in an article published in Geochimica et Cosmochimica Acta Volume 69, Issue 21 titled The Escanaba Trough, Gorda Ridge hydrothermal system: Temporal stability and subseafloor complexity, by first author K.L. Von Damm. The results of this paper suggest the "hydrothermal system is being driven by subsurface magma, as evidenced by elevated He/heat ratios, relatively high concentrations of He, and chloride contents less than seawater in the hydrothermal fluids"(Von Damm).

MBARI conducted their tests from samples of the active hydrothermal system in Gorda Ridge retrieved by the ROV *Tiburon*. The recent sample, collected in 2002, of the vent remains unchanged from the only time this field was previously sampled in 1988(Von Damm). Results from the sampling "provide information on the mineralogy and composition of materials below the seafloor, as well as the physical conditions occurring below the seafloor hydrothermal system" (Von Damm). Calculations suggest equilibrium between the fluids of the vent and the substrate, which support the fact that the fluids have remained chemically stable for 14years (Von Damm). MBARI researchers found that the "hydrology and chemistry of the hydrothermal system are much more complex within the sediment cover than would be expected from the surface manifestations of the hydrothermal system" (Von Damm). They conclude that the fluids with chlorinity greater than seawater are actually less dense than the fluids with chlorinity less than seawater. This explains why the fluids with greater chlorinity are venting preferentially to the less chlorinated fluids, which is opposite from the situation that is usually observed in similar systems (Von Damm).

MBARI scientists where greatly assisted in their research by the ROV *Tiburon*. This vehicle was uniquely developed at the institution and is shown in Figure 9 below. *Tiburon* provides many powerful features used for precise sampling and data collection in a variety of missions (www.mbari.org). The ROV is modular, with mission-specific tools that can be changed out quickly. *Tiburon* has high resolution video cameras, and scientific sensors and data logging integrated into the core vehicle system. The manipulator on-board *Tiburon* is capable of multiple tasks including collecting samples and deploying tools. *Tiburon* also has "provision for placement, servicing and retrieval of bottom-mounted instrument packages" (www.mbari.org).

Figure 9: MBARI's ROV *Tiburon*

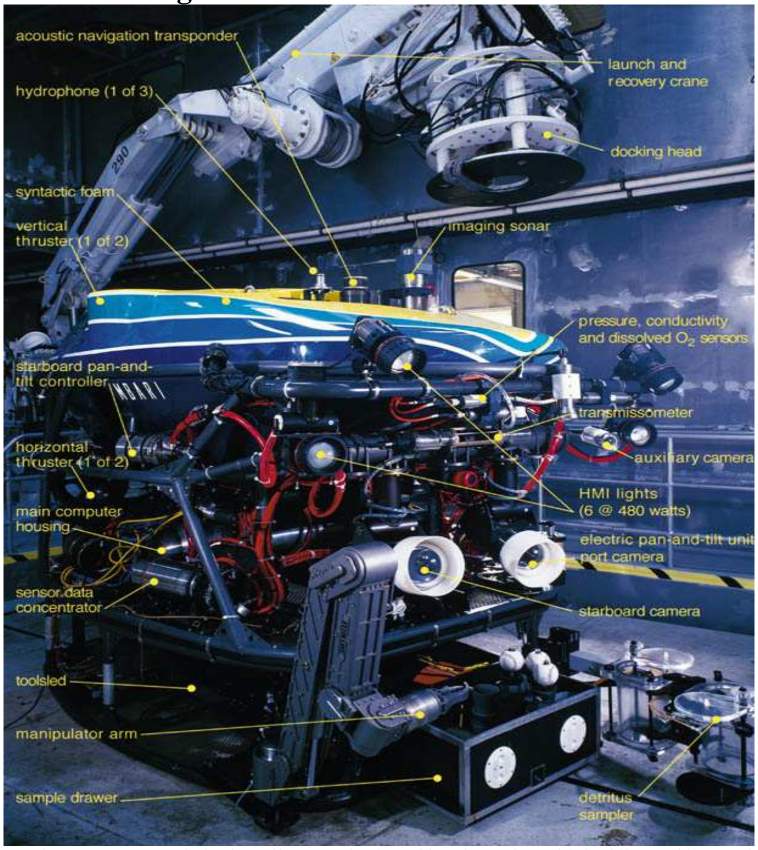


*photo from MBARI website http://www.mbari.org/dmo/vessels_vehicles/tiburon/tiburon.html

Our team modeled much of our design from the MBARI's *Tiburon*. The ROV *Sea-Slug* is similar to *Tiburon* in frame design and capabilities. *Tiburon*'s skeleton was built to support its many modular features, and is topped with a large floatation device seen in Figure 10 and 11 below.

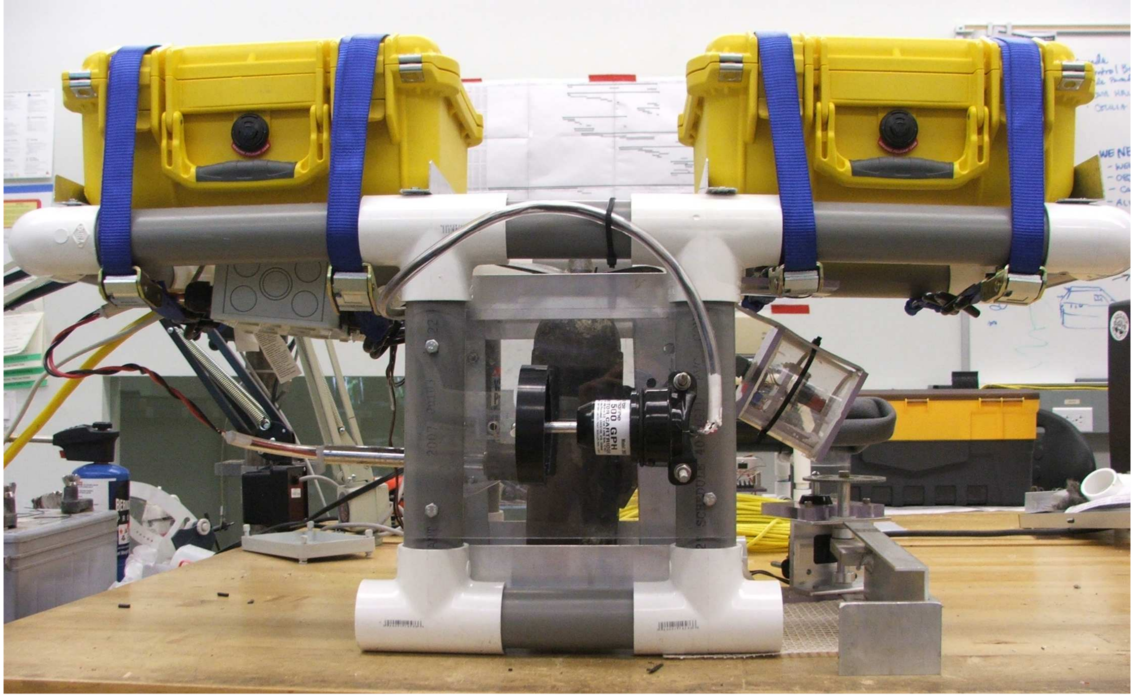
Figure 10: Frame of *Tiburon*

Figure 11: *Tiburon's* Floatation

*photos from MBARI website http://www.mbari.org/dmo/vessels_vehicles/tiburon/tiburon.html

We took a similar approach with the design of *Sea-Slug's* frame. Our PVC skeleton holds the thrusters, floatation, sensor circuits, and manipulator arm seen in Figure 12.

Figure 12: *Sea-Slug* Frame and Floatation



Our floatation devices are two large Pelican cases set fore and aft of the vertical thruster, much like *Tiburon*. The manipulator of *Sea-Slug* also has multiple functions like that used by MBARI. We are able to collect samples at any water level including the bottom of the ocean or a pool due to the strategic mounting of the arm. The sensor readings are also taken from the end of our manipulator, allowing us to move the sensors in the range of the arm without having to run the thrusters constantly to keep the craft stable. *Sea-Slug's* arm is also capable of lifting objects underwater by fully extending the arm under an object and using the thruster power to lift it upward. The ROV *Sea-Slug* is similar to MBARI's *Tiburon*, but very simple in comparison.

Reflections:

This project has also taught us a lot about practical engineering. We had the opportunity to actually start a design and do everything we would do as professionals; design in OrCad, shop for and order parts, program, build and solder circuits, and test. These skills have given us the confidence in our abilities to do proper engineering and deliver a finished product. It has also shown us that engineering education is not all about learning the answers, but instead how to approach a problem. Our success as engineers will not be due to the content of our education, but the thought process we develop through projects like this one.

References:

- Monterey Bay Aquarium Research Institute. http://www.mbari.org/dmo/vessels_vehicles/tiburon/tiburon.html.
- Von Damm, K.L., C.M. Parker, R.A. Zierenberg, M.D. Lilley, E.J. Olson, D.A. Clague and J.S. McClain (2005) The Escanaba Trough, Gorda Ridge hydrothermal system: Temporal stability and subseafloor complexity, *Geochimica et Cosmochimica Acta*, 69:21, 4971-4984.

Acknowledgements:

We would first like to thank Professors Stephen Petersen and Kenneth Laws, and our TA David Munday who have encouraged us from the beginning. We knew we had a short time constraint to make the competition and class deadline, but they always supported us.

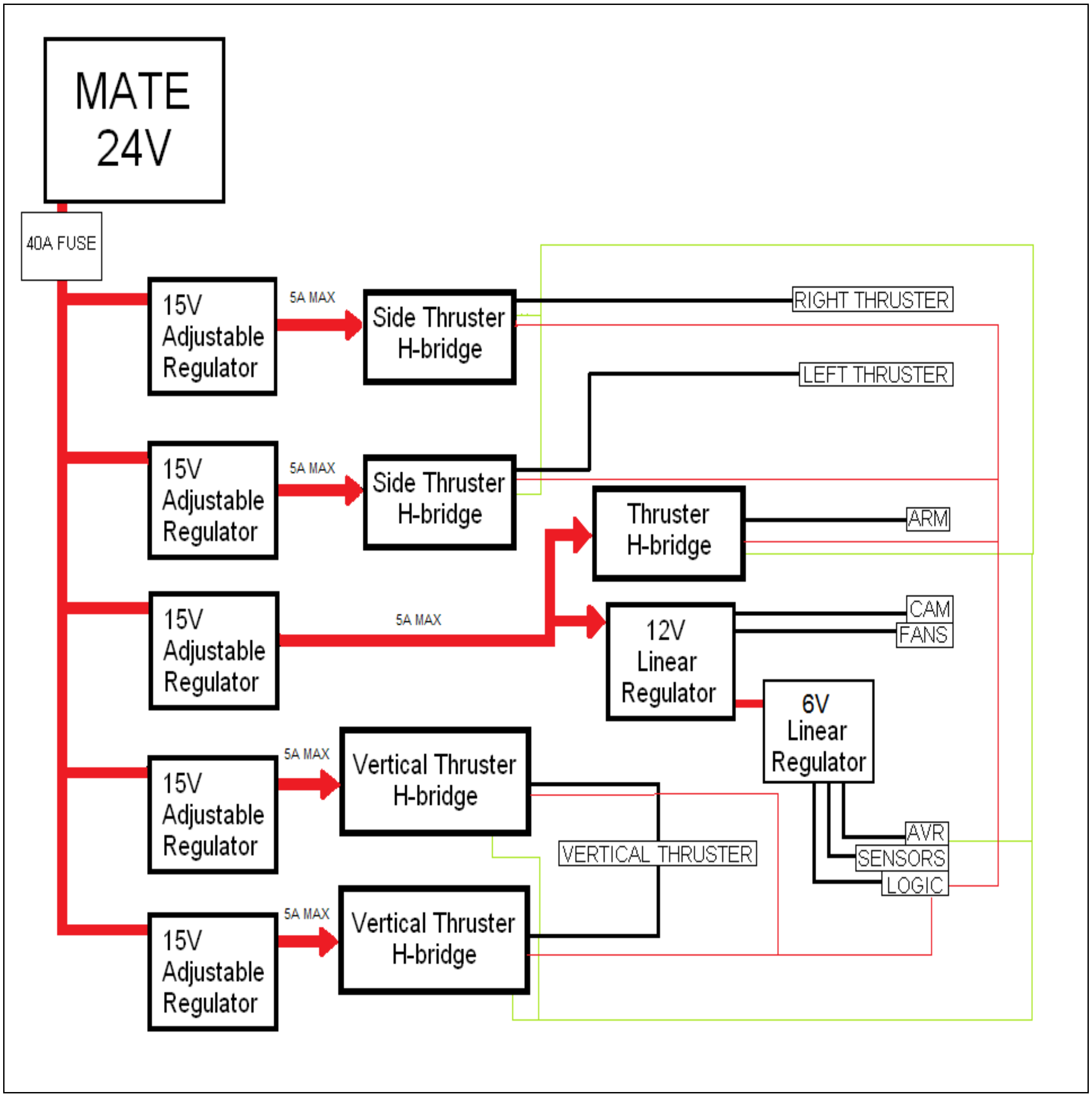
Thank you to the Dave and Darrell in the Machine Shop at UCSC for helping with the design and construction of the mechanical aspects of our ROV.

The Monterey Bay Aquarium Research Institute played a very large role in our inspiration for this project. When we began the design process, they invited us to their facility and gave us a first hand look at how they build their ROVs and control systems. Alana Sherman personally met with our team to discuss design considerations and helped us focus on how we could use our abilities to achieve the computer, electrical, and mechanical functions we wanted our ROV to have.

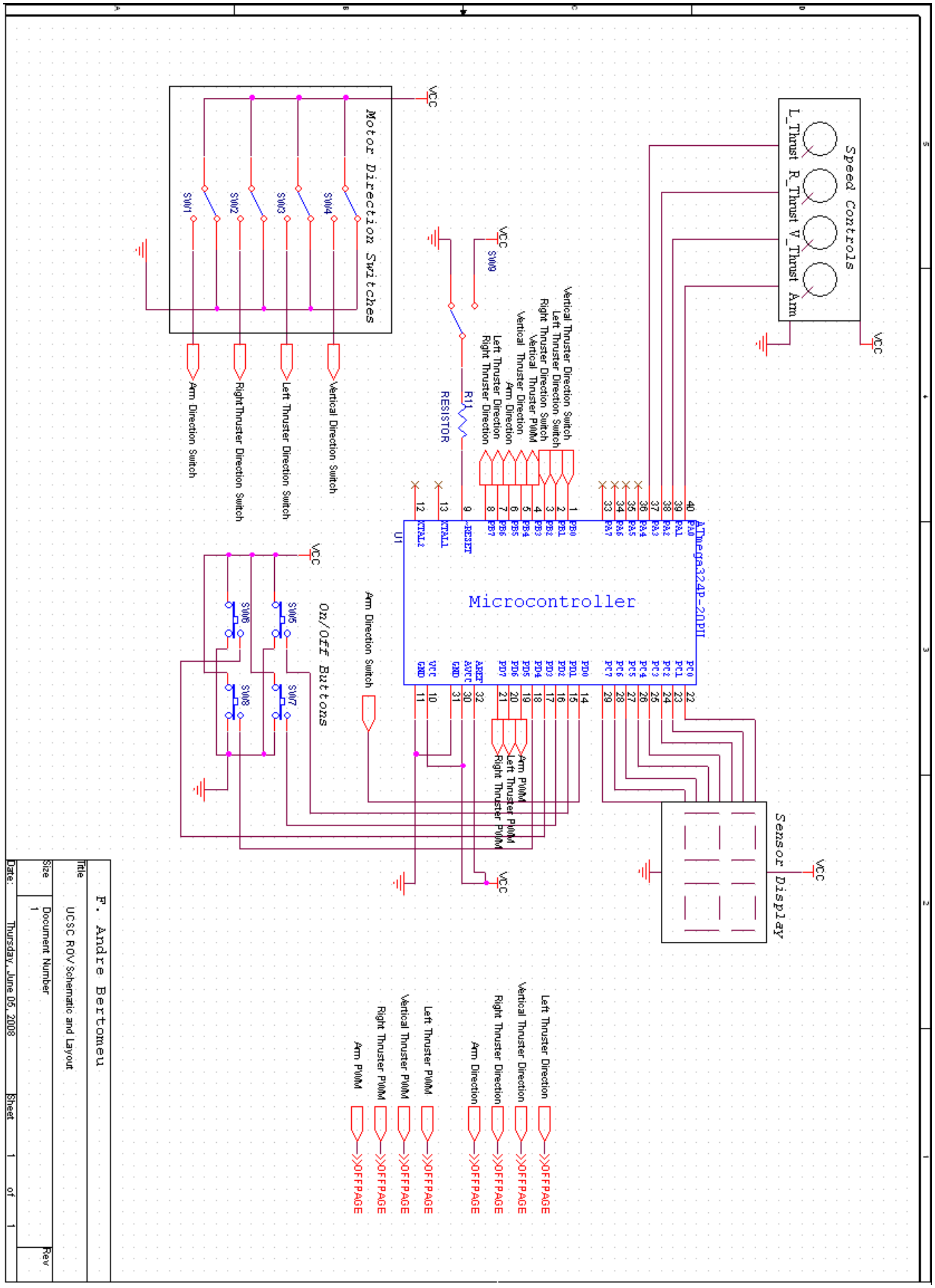
Thank you to Sound Ocean Systems Inc. for donating our 60ft long tether. Thank you to Pelican for donating two Pelican cases to the project as floatation devices for *Sea-Slug*. Finally, thank you to Cowell College for donating funds to support our project.

Appendix A: Electrical schematics

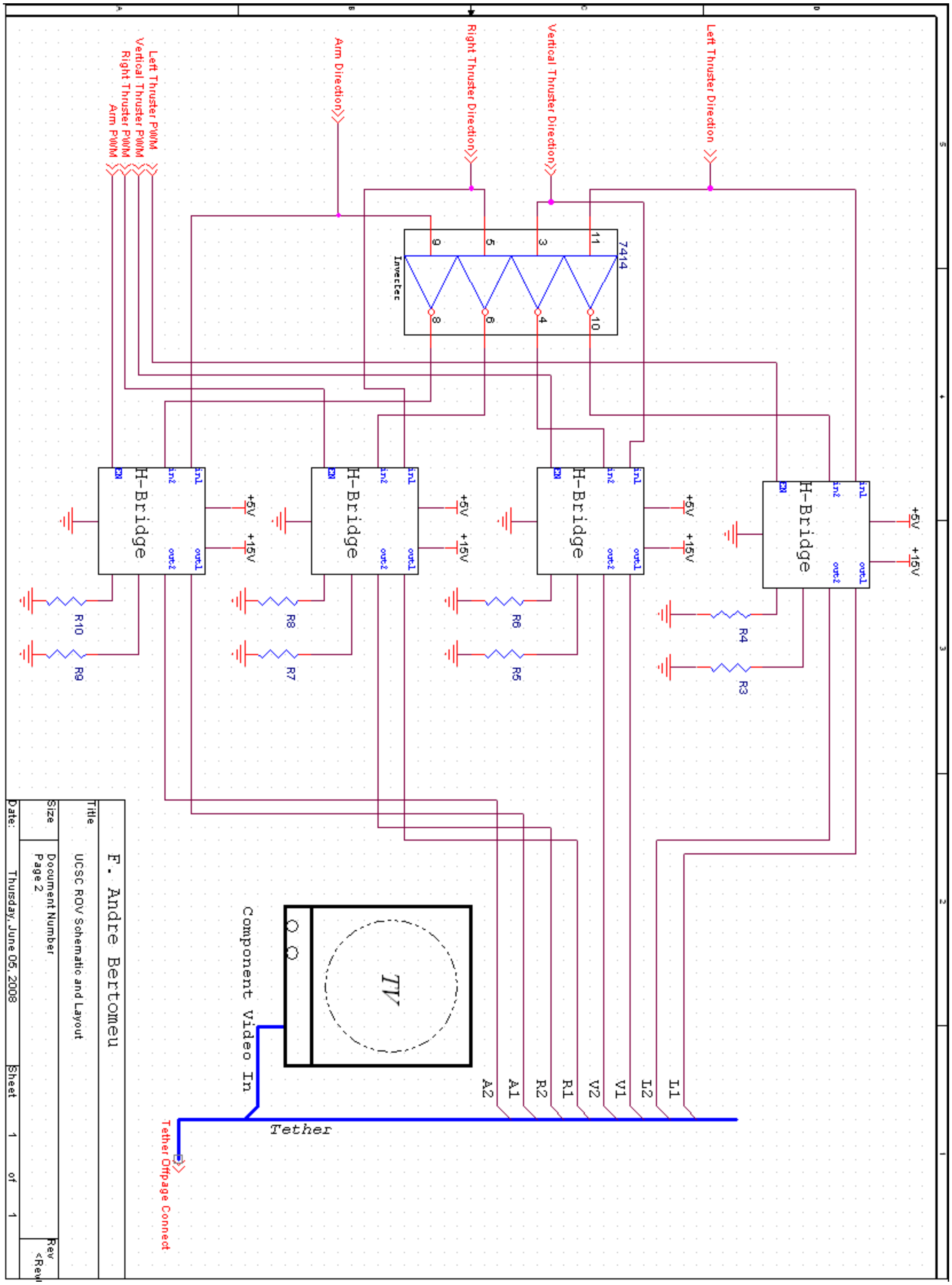
A1: Electrical and Power schematic



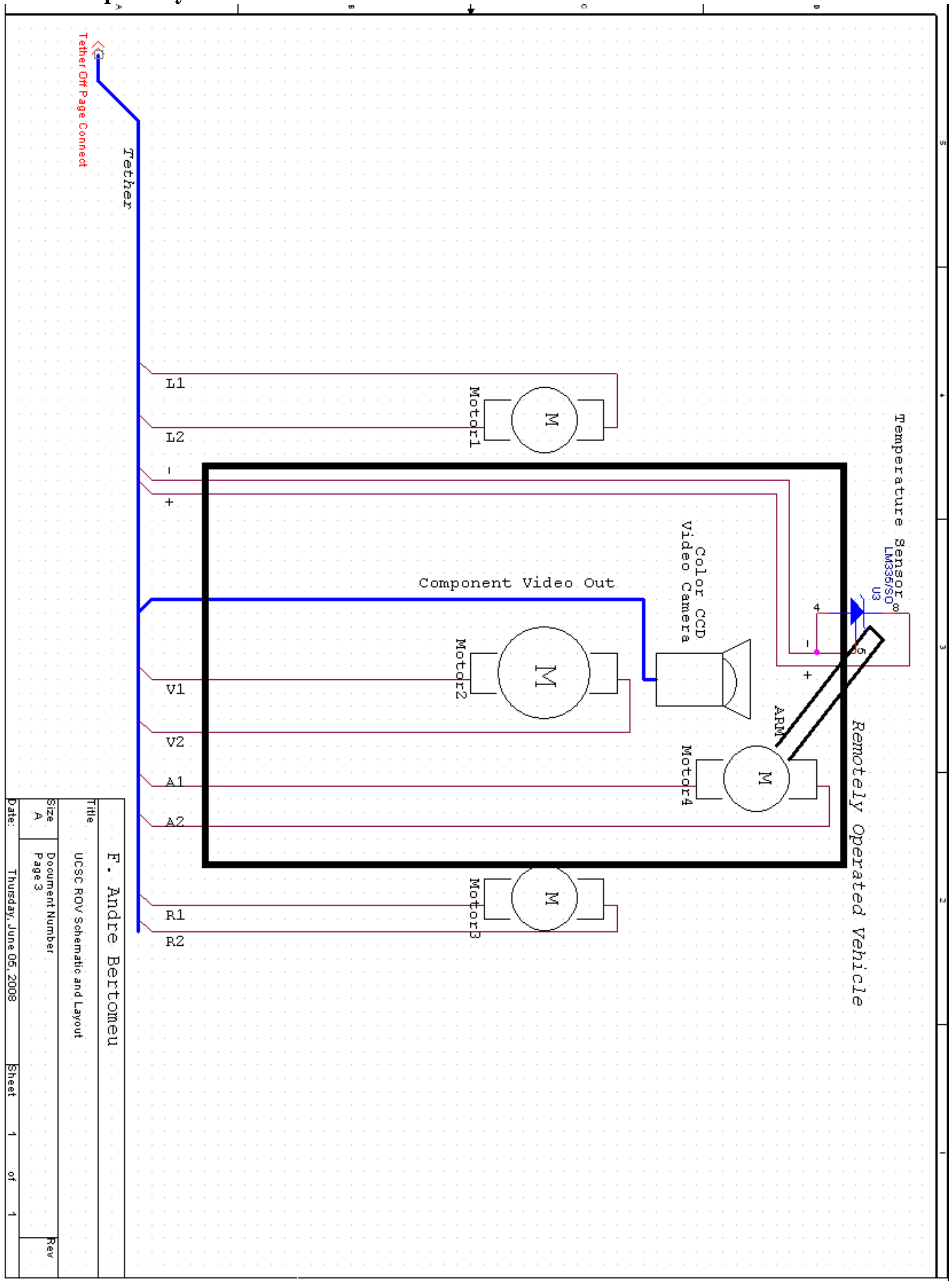
A2: AVR microcontroller schematic



A3: Thruster and video schematic

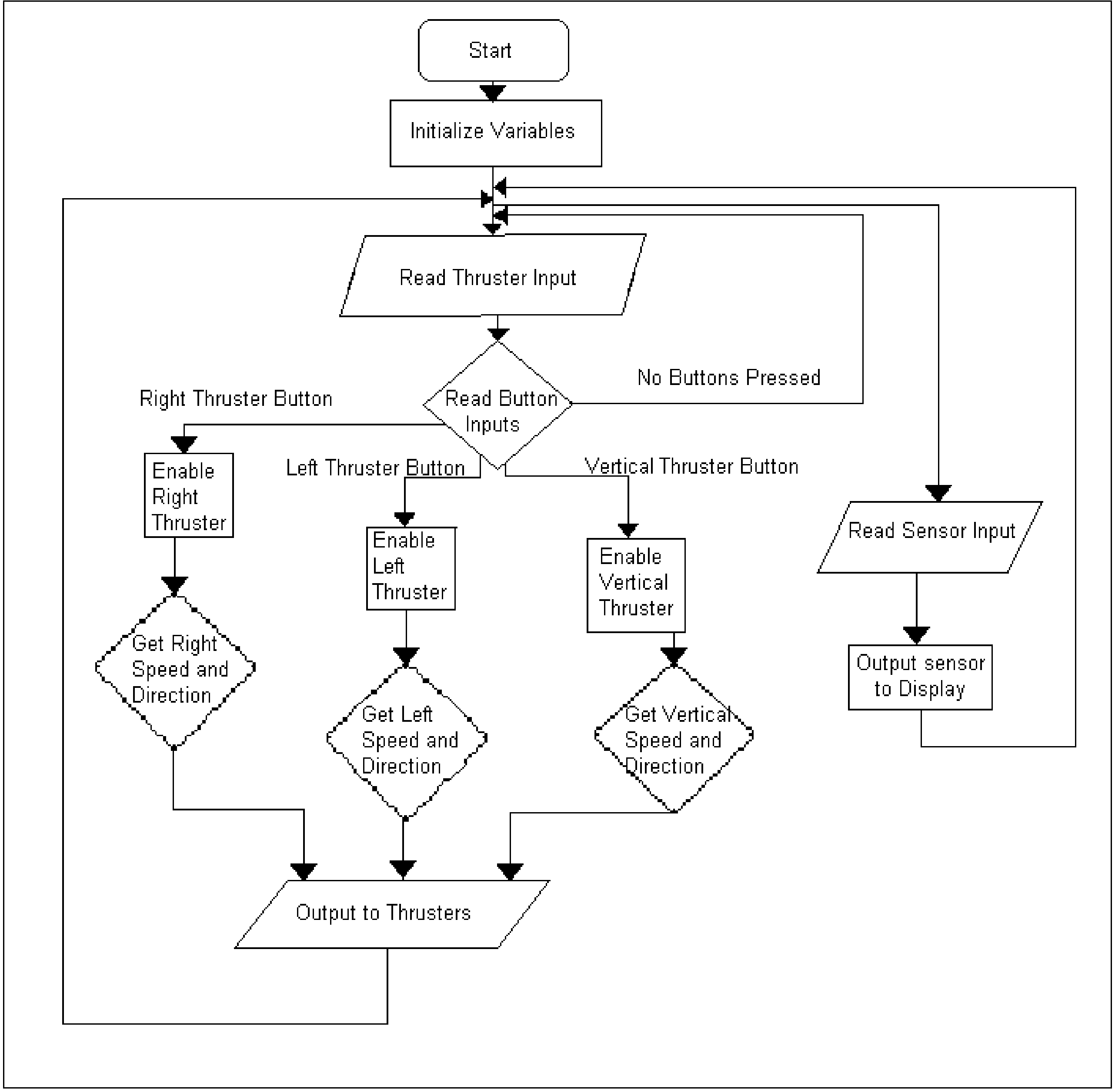


A4: Complete system schematic



Appendix B: Block diagram of Software:

B1: Software block diagram



Appendix C:

C1: Budget Sheet

Item	Quantity	Rate	Cost	Donation
Dive weights	4	$10.25 ea	$41.00	
SOSI umbilical	60ft		Shipping: $15.00	60ft
Atmega324P microcontroller	3	$7.33 ea	$22.00	
AVR Dragon Devboard	2	$54.50 ea	$109.00	
Buck Converters	3	$11.67 ea	$35.00	
Zif Sockets	2	$12.00 ea	$24.00	
Aluminum parts	88ft		$56.00	
PVC parts			$76.00	
Nuts & bolts			$24.00	
Tie-down straps	4	$5.00 ea	$20.00	
Marine Epoxy	1		$5.00	
CCD Color Camera	1		$43.00	
CCD Black/white Camera	2	$19.00 ea	$38.00	
750 GPH Bilge pump Motors	2	$25.00 ea	$50.00	
500 GPH Bilge Pump Motors	3	$20.00 ea	$60.00	
Waterproofing materials	Tubing, sealant		$26.00	
Wire			$7.50	
Control switches and buttons			$32.50	
Modeling foam	1 package		$9.00	
Pelican Cases	2	$100.00 ea	$0.00	$200
Shop Time	22hrs	$9/hr	$200.00	
Netting	2 yrds	$4.50/yrd	$9.00	
Discreet parts			$104.00	
Travel expenses:				
Food	2 days	$10/meal	$240.00	
Gas	1000 miles	$4.50/gallon	$350.00	
Total cost			**$1,596.00**	