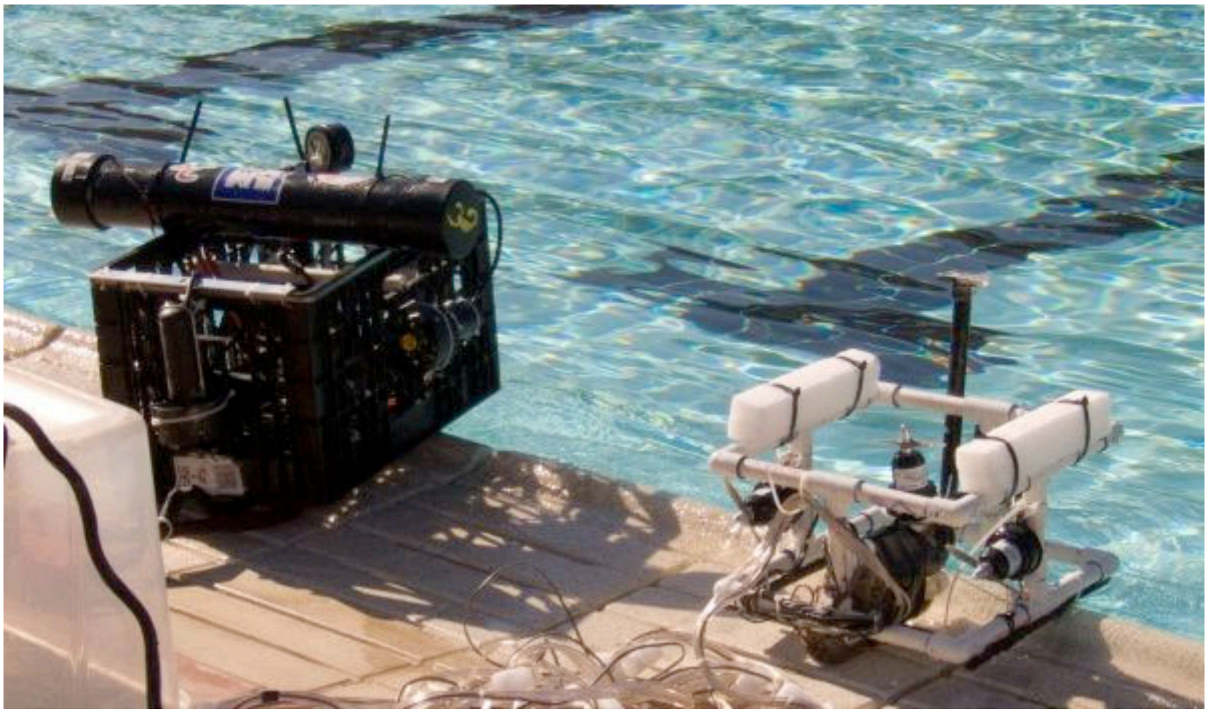
ARIZONA STATE UNIVERSITY
NASA SPACE GRANT ROBOTICS
TEMPE, AZ



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"Sub Aqua, Scientia"

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1. Abstract

The NASA Space Grant Robotics (SGR) team is composed of thirty undergraduate students and is now in their second year of designing robots for underwater applications. Last year, the team traveled to Boston to participate in the Marine Advanced Technology Education (MATE) underwater robotics competition. Here, SGR competed against 27 other universities in an underwater robotics competition. The competition serves as a means by which students are able to test the effectiveness of their engineering designs, meet other students from across the world, discover new ways of solving problems from other teams, network with industry and academic professionals, and become exposed to a real atmosphere for underwater exploration.

This year the team will be travelling to the Big Island of Hawai'i to participate in the 2010 competition. The focus of this year's competition will be the role of remotely operated vehicles (ROV's) in the exploration of the Loihi Seamount. Specifically, the mission will focus on how ROVs can be used to examine the life that is thriving in this hypothermic environment. The following report details how SGR made improvements to their designs from last year in order to build a more effective and efficient ROV capable of exploring the Loihi Seamount.

2. Expenses: NASA/ASU Space Grant Robotics

At the beginning of the year, a budget was created to keep track of finances. In the end, the total cost of the ROV was lower than expected. The total budget was broken down to account for the individual systems that would be needed, as indicated in Figure 1. Each sub-team was allocated an amount of expected funds for both the prototyping and the final system. As the year progressed, we carefully kept track of our actual expenditures as compared with the budget. Figure 2 shows the final summary of team expenses. A detailed budget is shown in Appendix A.

Figure 1: Breakdown of the planned budget by component

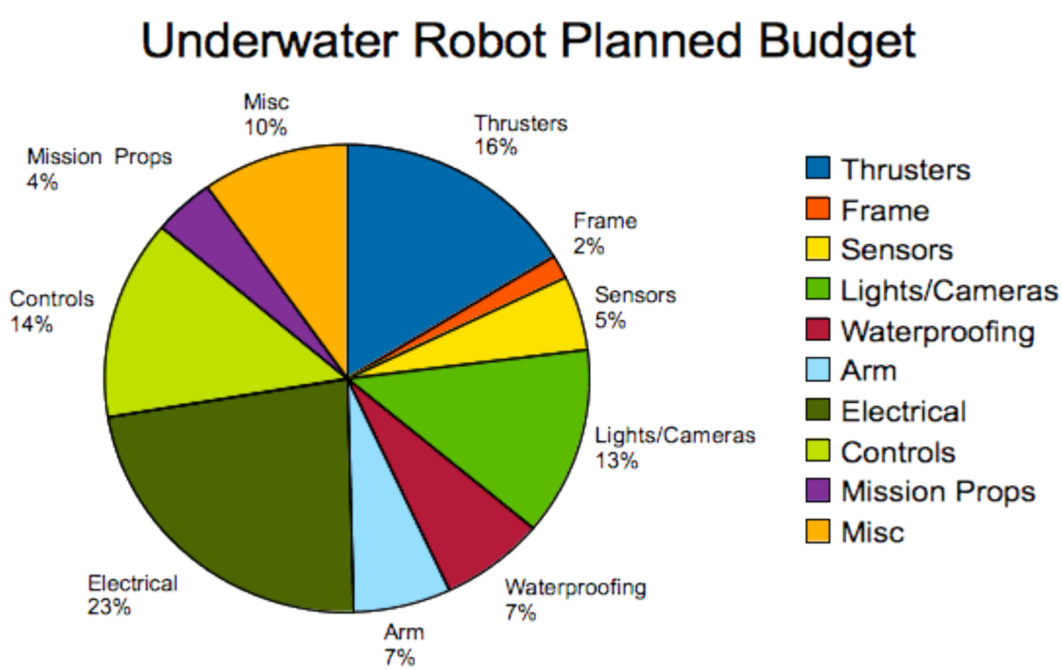


Figure 2: Summary of expenses

Total Budget	$6,076.70
Other Projects	$810.48
Spent	$1,943.02
Balance	$3,323.20

3. Design Rationale

3.1. Electrical System

The electrical system for our ROV consists of two main components: the power box and the control box. The ROV is rated to operate at 12 volts direct current (VDC). The power box, depending on the application, may run on 48 VDC from the surface or 12 VDC batteries on board the ROV.

In order to utilize 48 VDC from the surface, the ROV employs four negative 48 VDC to 12 VDC, 5 VDC, and 3 VDC DC-to-DC converters. The converters are from computer power supplies in the telecommunications industry, which uses a negative 48 VDC systems rather than a positive 48 VDC system. However, since the converter is DC, the inputs can simply be switched and the outputs switched as well for the same result. The supplied 48 VDC is routed through a 7-amp fuse, then the positive lead is routed through the negative input on the voltage converter and the ground from the surface is routed to the positive input on the voltage converter. (See Appendix B.) The resulting 12 VDC is then routed to the control box.

For the batteries on board option, the power box is refitted with four 3s Lithium Polymer (LiPo) batteries. Each cell in the LiPo battery is rated at 3.7 VDC, so 3 × 3.7 VDC yields 11.1 VDC. Each LiPo battery is rated at 5000 milliamp-hours (mAh) or 5 amp-hours (Ah) combined in parallel yields 20 Ah. (4 × 5 Ah = 20 Ah) Each LiPo battery is fused at 10 amps; then the fused connections are passed on to the control box.

Inside the control box the power connection from the power box is passed into a 12-position fuse panel for further protection of individual systems. Systems within the control box are separated into these five categories: Cameras, Lights, Motor Control, Microcontroller, and Sensors. Each camera is fused at 5 amps, and each video feed is sent to the surface via RJ-45 cable the video baluns.

The microcontroller of choice for this ROV is the Arduino Mega, for its four serial ports, 54 digital input / output (IO) pins, of which 14 provide pulse-width modulation (PWM), and 16 analog inputs. The Arduino Mega is protected with a 5-amp fuse and provides 5 VDC and 3.3 VDC, via an on-board voltage regulator, to the sensors on the ROV.

The sensors on the ROV contain a compass sensor, a temperature sensor, and a pressure sensor. The compass sensor uses the I^2C communication protocol to communicate with the Arduino MEGA. The compass has half-degree heading resolution, 1 to 20 Hz selectable update rate, and one-degree repeatability. The temperature sensor has a linear response for 5 to 32 VDC and one volt per degree Celsius. The pressure sensor uses a three-wire interface to the Arduino MEGA and can measure 0-14 bar absolute pressure.

For speed control, our ROV utilizes three dual-channel Sabertooth speed controllers. Each channel of a Sabertooth speed controller is capable of peak output current of 15 amps and a normal output current of 10 amps from 6 to 25 VDC. Each Sabertooth speed controller is protected with a 20-amp fuse. Two signal lines pass from each speed controller to the Arduino Mega microcontroller. For single direction speed control, the ROV utilizes a 30 amp brushed speed controller from TURINGY industries. The TURINGY speed controller receives a single signal line from the Arduino Mega.

A BuckPuck constant current driver powers the three Luxeon Star LED arrays in parallel while receiving a signal for the current level via a signal line from the Arduino Mega. For a full schematic, check Appendix B.

For safety reasons, the power connectors are interlocking, and each voltage wire can only connect with a correspondingly correct voltage. There are fuses, fuse panels, and each component is individually fused. Due to the potentially dangerous nature of the batteries, they are isolated in the power box.

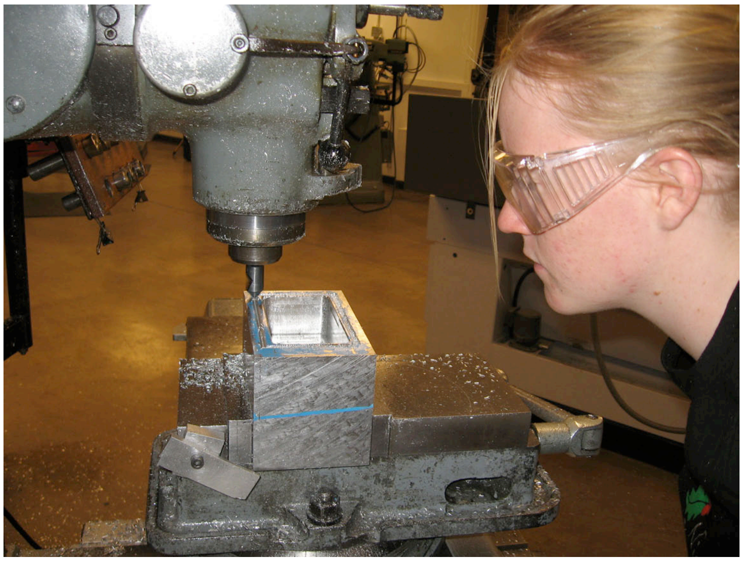
3.1.1. Electronics' Housing

Without the electronics, a robot is nothing. Without the correct waterproofed housing, the electronics are incapacitated and useless; thus, waterproofing is an integral part of the robot building process. To begin with, we wanted to create a polycarbonate cylindrical housing. The advantage of the polycarbonate was that it is transparent, making it easier not only to see the components, but to have an additional placement option for a camera. This would eliminate a possible point of failure because the camera would not need to be waterproofed. Polycarbonate is also easier to machine and to work with, making it far more advantageous for any changes we would need to make in the design process. Polycarbonate is strong and can withstand a large amount of pressure, useful for deep underwater dives.

The advantage of having a cylindrical housing shape is to have a more custom fit for the electronics, which would eliminate the potential for excess air to create too much buoyancy. To seal the cylindrical polycarbonate, we would machine two custom aluminum end caps, which would be sealed with two O-rings each, creating a double seal.

To first test out the custom end caps we initially used a four-inch AMS tubing. In the testing phase, we ran into a few problems. The AMS tubing was not cylindrically uniform, and the machining with the custom end caps became a trial-and-error process to get the proper watertight fit. When we tried to implement the design, we discovered the end cap went too deep into the tubing itself, so the volume of air inside the capsule had to be compressed 20% to get the seal correctly in place. This was a major problem, and we could not put the end cap correctly in the tubing to create the seal because of the pressure created. We looked into having an air release valve on the side of the tubing to release pressure during the closing and opening of the tube. This could create another point of failure on the control box.

Figure 3: Building the custom housing



During the design process, we had to change our plans because of the underwater connectors we would be using. To wire the robot effectively, we needed twenty underwater connectors, which would have to be assembled on a flat surface. This eliminates the effectiveness of having a cylindrical housing.

Instead of the cylindrical polycarbonate housing, we are making an aluminum rectangular box, open-ended at the top. A polycarbonate sheet will cover the open end to allow for better viewing, sealed with an O-ring. The location of the O-ring at the top would correct the earlier problem of created air pressure because we would have to compress very little air. Thus, this would make it very accessible. Like the original polycarbonate housing, this allows for an additional option for mounting a camera without having to waterproof the camera, eliminating a possible source of error. The rectangular shape provides a large amount of flat space for placement of the underwater connectors, which can eliminate the need for excess wire. Because the housing will be made out of aluminum, it can withstand larger amounts of pressure and go further underwater without losing its shape. It is easier to machine and mount electronics in the housing as well as provides better integration into the frame and overall design. The cylindrical housing would have been harder to mount in the frame design of the robot.

3.1.2. Surface Control Software

The software running on the pilot's computer is responsible for driving the robot, interpreting the current controller input, and displaying the current compass direction, the depth, and the remaining competition time. It uses the Windows Presentation Foundation framework available in the newer versions of .NET. The controller input is accessed using Microsoft's XNA Game Studio framework, which provides an easy interface to Xbox controllers. The controller was connected to the computer, and the six axes of control were mapped to different drive capabilities of the robot. To communicate though the serial port, .NET provides a easy to use serial port class to simplify the setup and communication code between the Arduino at one end, and an available RS-232 port on the other. Behind the scenes, the software uses two additional threads to operate. The first worker thread is responsible for polling the controller, updating the UI and communicating to the ROV control class. The second thread, the serial thread, asynchronously receives updates from the worker thread and sends the updated control input values to the ROV, and reports any communication errors to the worker thread. To implement these threads along with the existing UI thread, safe cross thread calls and mutex protection were necessary. For a full schematic, see Appendix C

The software is comprised of a dozen classes, three threads and about three thousand lines of code. The software has been in development for about two months and will continue to be developed even after the competition to provide control for future robots of all types.

3.2. Sensors

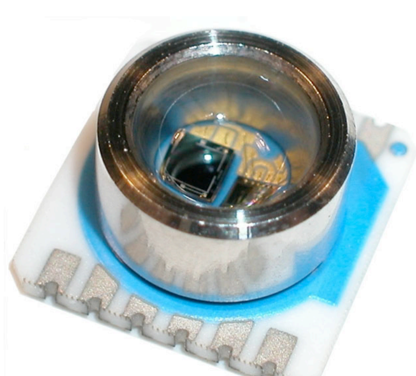


Figure 4: Pressure Sensor

Two types of environmental sensors are used for this ROV: a temperature sensor and a pressure sensor. The temperature sensor is required for tasks in both the MATE and NURC competitions, with a required accuracy of 5 °C. The pressure sensor is used to determine the depth of the ROV. This measurement has two purposes: First, one task in the NURC competition requires measuring depth to within

5cm, and second, knowing the ROV's depth allows an automatic system to maintain the ROV at a constant depth while the pilot focuses on navigation in the other two dimensions.

The pressure sensor used was an MS5535 temperature-compensated waterproof sensor. This module includes a temperature sensor and has onboard calibration data that can be used to effectively eliminate errors due to water temperature. The requirement for this sensor was that it be able to measure pressure to sufficient accuracy to measure depth to within 5 cm, which, given the density of water, requires a precision of 0.5 kPa. Under the pressure and temperature conditions that the ROV will be working in, the MS5535 has a maximum error of around 0.5 kPa. This is still higher than we would like, but we intend to further reduce the error by averaging several measurements in a row.

The temperature sensor is an LM35 precision centigrade temperature sensor. This sensor is not waterproof, so it is housed in a hollow copper cylinder sealed off at one end with silicon and filled with a heat-conducting compound. The copper cylinder will protect the sensor and wiring from water, while still allowing the sensor to reach the same temperature as the water within a few seconds. This temperature sensor has an accuracy of 0.5 °C and an operating range of -55 to 150 °C . It outputs a voltage that is linearly proportional to the Celsius temperature, with a 10 mV change corresponding to 1 °C, and comes pre-calibrated with 0 °C set to a 0 V output.

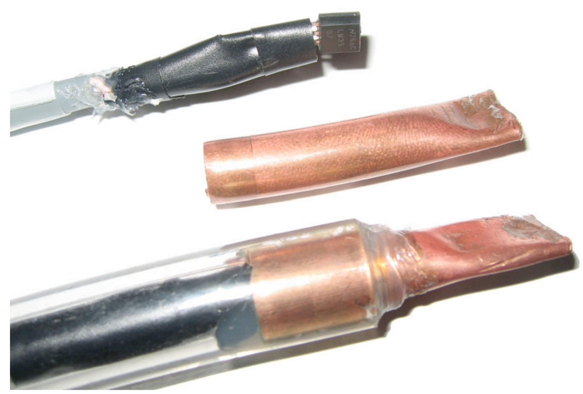


Figure 5: The Temperature Sensor

3.3. Manipulators

3.3.1. Agar Collector

The agar collector consists of a medicine bottle that is cut to fit 140 mL of liquid. This size is the best to keep within the 100 to 175 mL range for collection. A tube is attached to a hole on the bottom of the bottle to allow air or water to be pushed through the bottle by the agar when it enters the bottle. A servo will pinch the tube, which will allow a vacuum to form in the tube when the agar attempts to slide out of the bottle. The result should be a near perfect cylinder of agar about 140 mL in volume, which can be brought to the surface without any problems. The bottle will be attached to a 1 ½ inch (38.1 mm) PVC pipe connected to the robot, with the tube running through it to the servo. This was chosen over any scooping method, which could be difficult to maneuver and still retrieve the correct amount of agar.

Figure 6: Sample of agar

3.3.2. Crustacean Collector

Instead of a net, a vacuum device will be used to collect crustaceans during the mission. The disadvantage of using a net is that the crustaceans could potentially fall out if the vehicle turns to sharply or accelerates. The vacuum ensures a quick and easy hold on the crustaceans with little chance of mishaps. The device consists of a short length of 1 ½ inch (38.1 mm) PVC pipe with a 1000 gallon per hour (4000 quarts) bilge pump attached. The bilge pump creates laminar flow in the pipe, which then creates suction at the intake. A nozzle made of 1 inch PVC angled 45° downward acts as a nozzle to enhance the vacuum. At the other end, a PVC tee section splits the exhaust in opposite directions. This causes equal amounts of water to be displaced in opposite directions. This equalizes any propulsive force that would occur if the outlet water were to be directed in only one direction. A small net is fitted over the exhaust port to capture any crustaceans that are sucked through the vacuum.

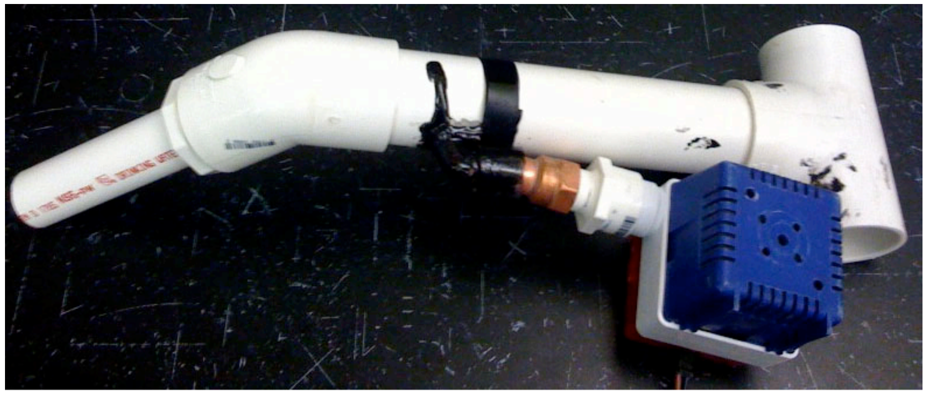


Figure 7: The Crustacean Collector

3.3.3. Arm

Figure 8: Robotic Arm

The main manipulator for the ROV is the robotic arm. A Seabotix arm proved effective and efficient for use during the 2009 competition, and it has been re-outfitted for use on the 2010 ROV. The robotic arm has a three-pronged claw at its end that opens and closes by applying a positive or negative voltage. The robotic arm is placed at the front of the robot, and there is a camera designated for observation of its claw. The main forward camera can be used to help provide an additional vantage point for observation of the claw.

The arm will be used to complete the majority of the mission requirements. For task 1, this includes removing the pins, grasping the connector, and removing the cap. For task 3, this includes collecting the sample and returning it to the surface.

3.4. Camera/Hydrophone

Figure 9: ROV camera

Figure 10: Camera housing

The audio/visual sensors for this year's ROV are vital to the completion of the tasks. Our A/V sensors this year include cameras, a hydrophone, and high-output lighting devices. The camera is a Super Circuit model #241XS.

Our robot uses an off-the-shelf seismic-grade hydrophone to transmit sound from underwater to the surface. The hydrophone selected yields a high frequency range, giving us the ability to hear a wide range of sounds emitted underwater. Our cameras are housed in custom PVC housings, which allow them a wide field of view while still protecting them from the water. The cameras selected have a fairly high resolution (520 lines), to give us a crisp picture and allow us to navigate underwater without confusion regarding object recognition.

3.5. Lighting

We are using Luxeon Star LED tri-emitters for our high intensity lights. These consist of three LEDs attached to a single board. We are incorporating these powerful LEDs into custom machined aluminum cases to provide both waterproofing and heat dispersion. The lighting system includes a constant-current converter circuit that maintains an adjustable light output regardless of the input current.

Figure 11: LED array

Figure 12: Power regulator

Our 'star' LED arrays are capable of emitting 540 lumens at 700 milliamps. We plan to have three lights incorporated into the robot, giving a total lumen output of 1620 lumens. Each light is equipped with a wide angle flood-style lens, giving a 25 degree beam angle.

3.6. Propulsion

Our goal last year for the next competition was to make custom waterproof thrusters. So this year we set to work on this goal. We decided to go with brushless Scorpion DC motors because they had more thrust power than the Seabotix thrusters. We were going to put Cyclone speed controllers within the waterproof housings as well as encoders to give the rate and the direction of the motor. This would allow us to compare encoder data of acceleration and gyro rotational values to better approximate position. The only disadvantage of our custom thrusters was that their increased thrust would only be in one direction, due to the propellers we were using. On the other hand, the Seabotix thrusters can go about the same speed in both directions.

In the end, due to time restraints, an understaffed subgroup, and having currently working thrusters, it was determined to be more efficient to use the Seabotix thrusters we already had and put our time and effort towards more pressing concerns.

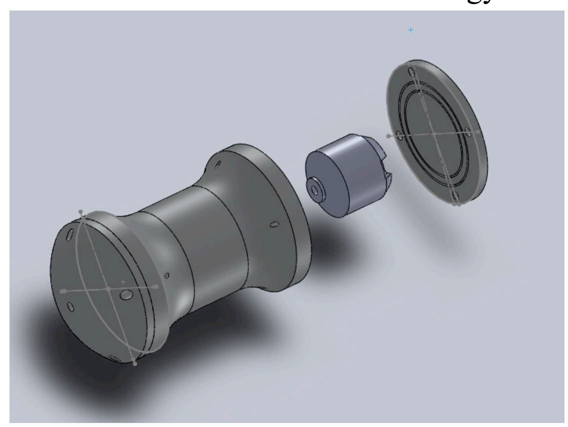


Figure 13: Custom Thruster in SolidWorks

3.7. Frame

Careful planning for the ROV's frame is vital, as every other component depends on the frame and attaches to it. Last year, our frame was a milk crate. The greatest advantage of the milk crate frame was that it allowed for rapid prototyping – that is, components were highly accessible and could be attached, detached, and repositioned quickly and easily. The milk crate was very low-cost, as it was donated to us by a local grocery store. The disadvantage of using a milk crate was that the frame was larger, heavier, and not hydrodynamic. We also could not change the structure of the frame at all; we were stuck with the size and shape of the milk crate.

This year, we are using a PVC frame. This allows for much more flexibility in frame design. PVC was chosen because it is strong but inexpensive. We decided to have the frame completely sealed, in order to trap air inside. This will provide some buoyancy and reduce the mass that must be moved by the thrusters.

3.8. Green Power

Green Charging this year will be achieved by using three sets of two panels each wired in series to attain 48 VDC, then each set of panels is wired in parallel to a battery bank of four 12 VDC sealed-lead-acid batteries also wired in series. The main reasoning for using 48 VDC over 12 VDC is there is more efficient when working with direct current over long ranges versus lower voltages. The 48 volt supply will then be stepped down using one 48 VDC to 12 VDC voltage converter. The 12VDC supply will be used to charge the LiPo batteries for use on-board our ROV. For a schematic of the wiring, see Appendix D.

Figure: 14 Solar Panels for Green Charging

4. A Challenge

After the success of the team's rookie year, an active recruitment doubled the size of the team. Although the team welcomed the influx of new students, meetings were then crowded with masses of students eager to start working on the robotics team. The challenge for the veteran members then became to find a way to quickly integrate the new members into roles that would help them get caught up to speed on the robotics as well as maintain their enthusiasm. If this were not properly managed, the team may have lost some valuable potential.

In order to ease the integration of so many people, two methods were implemented. First, the robotics team decided to expand its projects beyond the NURC and MATE underwater robotics competitions, to include land based robots as well. NASA Space Grant Robotics and Daedalus @ ASU joined forces to cooperatively enter the University Student Launch Initiative (USLI) competition. This competition focuses on carrying a scientific payload up a mile on a sounding rocket. It was decided that a transforming robotic rover would be a perfect scientific payload for the rocket. The rover would be jettisoned out of the rocket at the altitude of one mile, deploy a parachute, land, unfold out of its launch tube, and rove around on the surface after receiving radioed commands –something that has not yet been seen in this competition. Daedalus @ ASU focused on the design of the launch vehicle, while NASA Space Grant Robotics focused on building the deployable rover. Unfortunately, halfway through the building of the robot, the Daedalus @ ASU team had to withdraw due to lack of funding. The half-built rover was then tabled until all underwater projects could be finished. However, this endeavor provided a project for many of the new students to focus upon, while the others focused on the underwater robotics.

The second method used to organize the team was the creation of subsystem teams. Veteran members were designated to lead each of the subsystems for the projects. New students were then assigned to one of the subsystems where a veteran member could help coach them. Through this method, many of the new students were able to learn new skills such as soldering, CAD modeling, and programming. Specialization of members toward a subsystem not only helps to organize and focus the efforts of the team, it also gives each member an aspect of the project to take personal pride in and a desire to see it designed to the best of their ability.

Therefore the challenge this year was learning how to involve a host of new team members. This challenge is actually one that is good for a new team to have – as long as it is managed properly.

4.1. Troubleshooting

When a problem arises, a number of steps are taken in order to ensure that a safe and efficient solution is implemented. The first step in solving a technical issue is usually to turn off power to the robot, in order to ensure that it is safe to examine it. Any other precautions are then taken to ensure that it is also safe to operate on the vehicle. Once it is safe to continue, the problem is then isolated to the subsystem to which it pertains. If necessary, measures are made to prevent the issue from spreading (e.g. water leaking into a component box). After the problem is properly isolated, an analysis is conducted to determine the exact cause of the problem using the "5 Whys" method, a five tiered chain of causality. Usually, the cause of any problem can be traced through several errors rather than the immediate superficial one. Once the causes are properly determined, adequate solutions are developed to ensure that these causes are fixed. If necessary, these solutions are applied to the various other subsystems and aspects of the robot to ensure that they do not repeat. Finally, the solutions are tested to verify that they cause of the problem was satisfactorily eliminated and did not create any new problems. Periodically, these implementations should be checked to confirm resolution. Finally, the problem, causes, and solutions are mentioned to the rest of the team to educate team members and prevent the mistake from reoccurring.

5. Future Improvements

Although many new improvements have been implemented to this year's ROV, it is probably the propulsion subsystem that will provide the main project for future improvements. Attempts were made last year to design custom thrusters; however, the waterproofing methods were not sufficient to ensure a watertight enclosure. Due to the constraints on time and resources, the team was not able to resume the design of custom thrusters this year. However, the team fully intends to pursue custom designs next season. These custom thrusters are beneficial for a number of reasons. Customizing the thrusters allows the team to design them for the optimum speed and torque, leading to a more agile robot. Better propellers can be ordered to provide far greater thrust. Finally, one of the projects that the team has worked on this semester is waterproofing of servos. These waterproofed servos can be integrated with custom thrusters in order to establish vector thrusting. If this system is equipped, the robot will then be able to gain a considerable level of dexterity with fewer thrusters. This system improvement is one that requires a considerable amount of research, design, and testing. The improvements of this semester – namely, the microcontroller-based control system – will help ensure that the team is ready to undertake this improvement next year!

6. Lessons Learned

At last year's MATE competition we received the Aloha Team Spirit Award for our teamwork, but that has not always been the case this year. In the process of making the control box for the electronics, there was information that wasn't shared between the groups working on the electronics, and those working on the waterproof box. This led to many frustrations, and several revisions of the overall design plan. The lack of communication between these two groups also affected the frame team and the camera team. In light of the time lost, materials wasted, and conflicts that arose, we improved our intersystem communication and put more energy into understanding the ROV as a whole system. We realized that the subsystems are interdependent on each other and that we had to communicate effectively to maximize our time and materials.

The most critical skill in building an underwater vehicle or robot is waterproofing. Last year, our entire design for our robot changed in the last three weeks before the competition because, one by one, each component failed due to improper waterproofing methods. Overuse of cheap epoxy, silicones, and insulating foams, as well as improper use of O-rings and wax, were ultimately the demise of our original robot. This year, we have fixed this by creating an entire team dedicated to improving the team's knowledge of waterproofing techniques. On our robot this year, we are employing the proper use of O-rings, after much help from our Parker Handbook of O-rings. We also learned how to machine a properly sized groove for the O-ring, not to the dimensions of the o-ring, but with a wider cut so the O-ring has area to be compressed into. The variable width and depth of the groove, as compared to the O-ring, was an important skill to learn. We are also learning how to use and create our own gaskets. We have realized the importance of a tampered thread insert because a straight threaded insert will not seal properly. Overall we have increased our knowledge of the proper materials to use when waterproofing and specific applications of different methods of waterproofing.

7. Reflections

As a new member of the NASGR team, I was uncertain of what role I would play. I was quickly assigned to the controls team and began helping with the electrical team as well. As time progressed, I began spending most of my time assembling electrical components and soldering, and I learned to make a hydrophone in the process. I have learned a lot about my strengths and weaknesses through this process and now realize I need to learn to code. I am also learning a lot of important hardware-related information from Alex and next year I hope to be more of an asset to the team.

-Scott Foster
Junior, Electrical Engineering

In the beginning of this year, my first as a college student, I didn't expect to get involved on campus; I expected to focus solely on schoolwork. I'm a liberal arts student, so I'd never before considered robotics as an extracurricular and never studied anything remotely like it. I started attending the meetings because a friend and member of the club asked me to try it out, and I ended up staying. Now, two semesters later, I've attempted to be of some help to the team, with mixed results, and I'm proud to say I'm a member. It wasn't what I expected, but I've been able to learn and help in the student machine shop, help build an ROV kit, solder, model in SolidWorks, test out some prototype parts, contributed to outreach programs at Homecoming and a local elementary school, and write some of the presentations and technical reports. Even though I wasn't experienced or prepared coming into this, I've learned many new skills and gained an interest in field I never would have found out about otherwise.

-Jamie Shawver
Freshman, Chinese major

8. Lo’ihi Seamount Research

The Hawaiian-Emperor chain, located in the Pacific basin, is the longest in the world with over 80 undersea volcanoes. The linear orientation and the bend of the chain show the age progression of its volcanoes, leading to the hypothesis that it was formed over a stationary mantle plume (Garcia et al., 2006). Located approximately 35 km off the southeast coast of the Big Island of Hawaii is the active Lo’ihi undersea volcano. Lo’ihi is the last part of a seamount chain in the Hawaiian hotspot. At its summit, the seamount stands more than 3,000 m above the sea floor (Rubin).

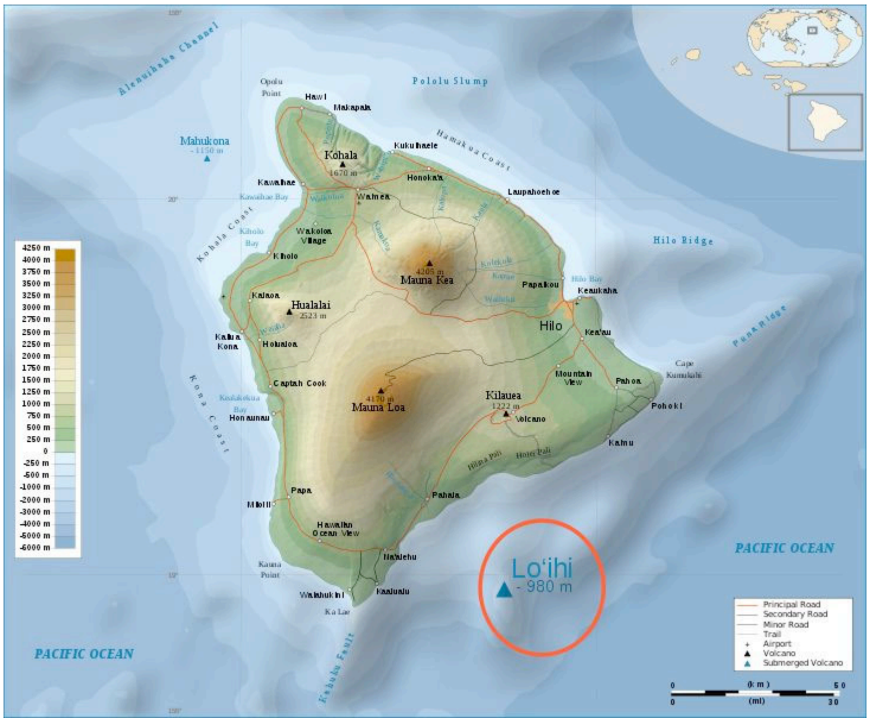


Figure 16: The location of Lo’ihi relative to Hawaii’s Big Island (from Wikimedia Commons, (http://commons.wikimedia.org/wiki/File:Hawaii_Island_topographic_map-en-loihi.svg)

Lo’ihi seamount was largely ignored until seismic activity in the 1970s, which prompted a marine expedition in 1978 to survey the seamount. It was then confirmed that it was a young and active volcano. Investigation revealed that the seamount is covered in lava flows and actively venting hydrothermal fluids, named “Pele’s Vents,” after the Hawaiian goddess of the volcano. These were renamed “Pele’s Pit” after this southern portion of the summit collapsed as a result of earthquakes and the withdrawal of magma from the volcano. The Pit has steep walls and is almost 300 m deep, and the quakes created new areas of hydrothermal venting. Within weeks of their creation, bacteria began colonizing the sites, and now diverse microbial mats surround the vents and cover the nearly vertical walls of the pit (Rubin).

These studies began two decades of exploration of Lo’ihi. In 1977, the Hawaii Undersea Geological Observatory (HUGO) was created to better monitor the seamount and collect data (Garcia et al., 2006). HUGO gave seismic, chemical, and visual data on the seamount. The initial instruments deployed included a high-rate hydrophone and pressure and temperature sensors. In

1998, however, the power cable flooded. It was repaired in 1999, and flooded again in 2002. It has not been repaired or made operational since.

On the island of Oahu, the Hawaii Undersea Research Laboratory (HURL) has two deep-diving submersibles and an ROV, the RCV150. The Pisces V, one of the submersibles has been conducting many exploratory and research missions to the seamount, through over 50 dives, to investigate its geology, volcanism, hydrothermal systems, and microbial communities by collecting data, sampling organisms, and repairing HUGO. The Pisces V and other vehicles have faced many challenges working in the dangerous terrain, and many tasks are abandoned due to unsafe conditions for the vehicle or crew.

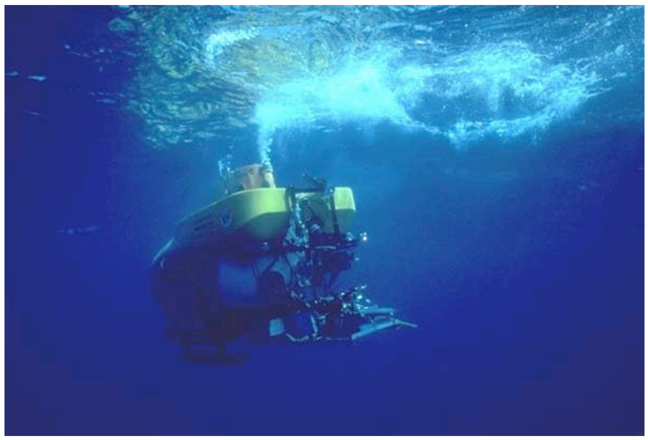


Figure 17: Hawai'i Undersea Research Lab's submersible Pisces V underwater about to dive (courtesy of http://oceanexplorer.noaa.gov/technology/subs/pisces/media/piscesv.html)

This competition is a good representation of the current status of HUGO and the recovery attempt being made by HURL. The tasks we will be performing in the competition are nearly identical to those being performed Pisces V, including: rescuing HUGO, taking hydrothermal vents site temperature readings, sampling bacteria, and measuring pressure. The work we're doing is directly useful for practice of real-life situational ROV building.

9. References

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Garcia, M.O., et al. (2006). Geology, geochemistry and earthquake history of Lȍihi Seamount, Hawaìi's youngest volcano. *Chemie der Erde – Geochemistry* 66(2), 81-108. <http://www.sciencedirect.com/...>, doi:10.1016/j.chemer.2005.09.002

10. Acknowledgments

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A special thanks goes out to Orbital Sciences Corporation for their generous donation of monetary resources and engineering mentorship. Our growing partnership has helped to provide a path by which students can practice hands-on engineering at the university and get guidance at the professional level.

We would like to recognize the support of the staff of the Mars Space Facility for all of their support and patience in all of our efforts. Special thanks go out to Meg "Mars Mom" Hufford for her invaluable support and supplies, to Scooby for helping us with posters and graphics, and to Chris Kurtz for all of the assistance with the computer lab, software, and electronic supplies.

The Space Grant Robotics team would also like to recognize the efforts of the NASA Space Grant office, which has supplied the resources and time to help initiate the robotics team. Thanks go out to Tom Sharp, Candace Jackson, and Danielle Pies. Without the combined effort of the space grant staff, this robotics team would not have started or have accomplished anything this past year.

Mark E. White has been monumental in the success of the space grant robotics team. He has donated hundreds of hours to help train the students in the arts of machining in a fun and exciting atmosphere. Without Mark's influence, we would never have learned how engineered designs become real hardware. Thanks Mark!

Shea Ferring has been largely responsible for the success of the Space Grant Robotics Team. His vision to expand hands-on engineering and professional mentorship to students has reached out to hundreds of students. Thanks for the push to expand robotics!

Dr. Phil Christensen has been a huge support for the robotics team. He has provided us with a base of operations for the team at the Mars Space Flight Facility, furnished the team with tools to work on the robot, and has spent time guiding the team and helping us out when in time of dire need. Dr. Chrisensen's vision to expand the educational experience amongst the college students is a praiseworthy characteristic that should be emulated in all college professors.

Appendix A: Detailed Budget

	Component breakdown				
	Category	Planned cost	Actual cost to date	Remaining budget	
	Thrusters	$600.00	$145.48	$454.52	
	Frame	$60.00	$47.05	$12.95	
	Sensors	$190.00	$131.69	$58.31	
	Lights/Cameras	$480.00	$398.79	$81.21	
	Waterproofing	$258.00	$83.14	$174.86	
	Arm	$240.00	$51.78	$188.22	
	Electrical	$840.00	$428.74	$411.26	
	Controls	$510.00	$202.47	$307.53	
	Mission Props	$150.00	$153.88	-$3.88	
	Misc	$360.00	$300.00	$60.00	
	TOTAL	**$3,688.00**	**$1,943.02**	**$1,909.38**	

	Funding Breakdown		
	Source	Amount	
	ASU-SORC (Fall)	$527.91	
	Space Grant Parts	$1,027.77	
	Intel Embedded	$2,500.00	
	MATE Prize	$50.00	
	ASU-SORC (Winter)	$768.30	
	ASU-SORC (Spring)	$1,202.72	

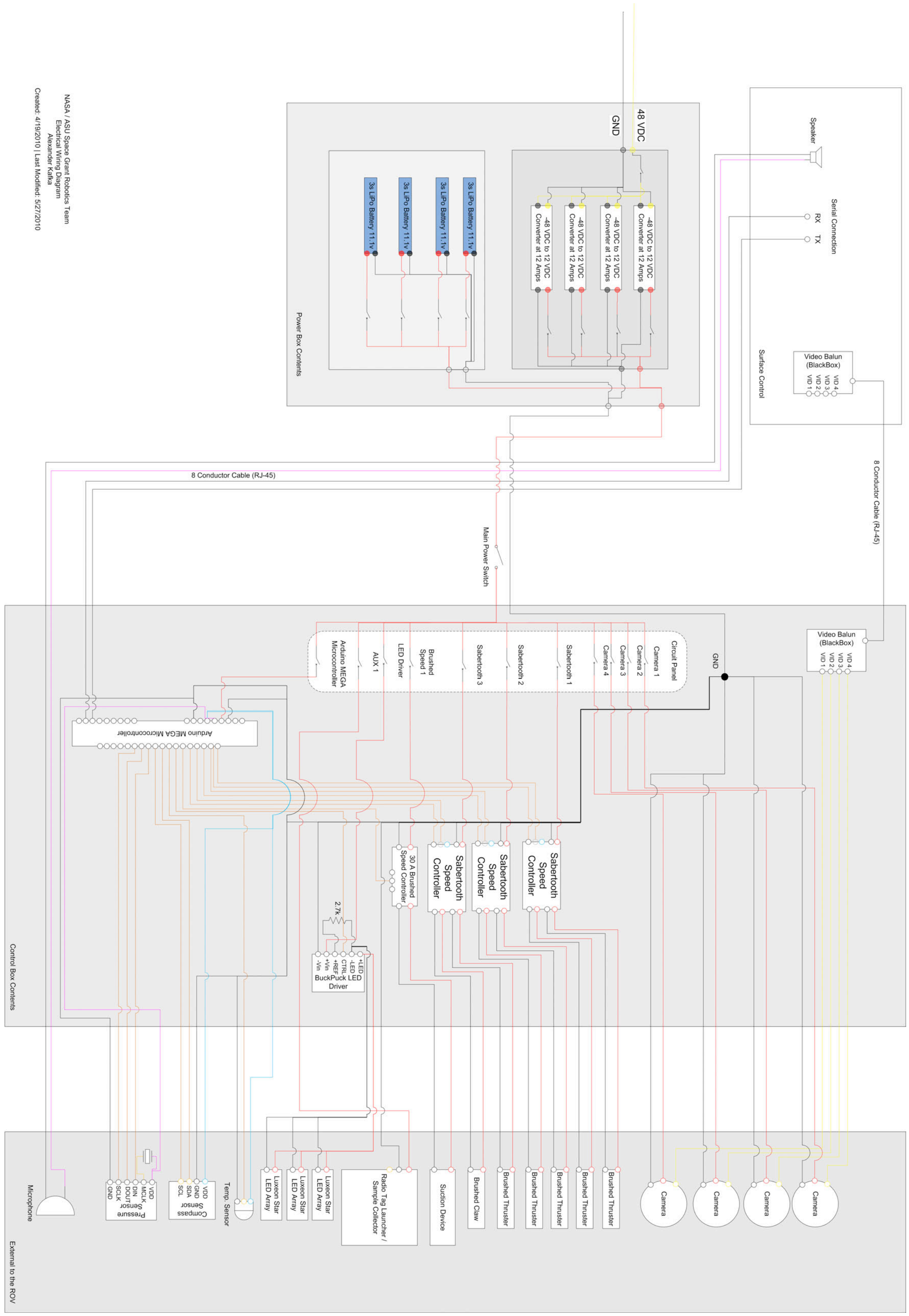
	Summary		
	Total Budget	$6,076.70	
	Other Projects	$810.48	
	Spent	$1,943.02	
	Balance	$3,323.20	

Detailed Breakdown				
Description	**Price**	**Category**	**Supplier**	**Date**
Speed Controllers (3)	$202.47	Controls	Dimension Engineering	12/02/09
NURC Registration	$300.00	Misc	APASE	01/21/10
MATE Field Equipment	$50.00	Props	Home Depot	01/26/10
MATE Field Equipment	$60.34	Props	Home Depot	01/26/10
MATE Field Equipment	$39.14	Props	Ace Hardware	01/31/10
MATE Field Equipment	$4.40	Props	Ace Hardware	02/10/10
Vacuum Parts	$32.38	Arm	MarineMax	03/15/10
Vacuum Parts	$19.40	Arm	Ace Hardware	03/15/10
Electrical housing/clamps	$33.22	Electrical	Powerwerx	03/09/10
Fuse Boxes, Connectors, Wire	$221.23	Electrical	Waytek Wire	03/10/10
Hydrophones	$25.00	Sensors	Paypal: boxq_ma	02/16/10
Hydrophones	$40.69	Sensors	Radioshack	03/11/10
MS5535C pressure sensors (2)	$66.00	Sensors	Servoflo	04/12/10
Pelican Boxes	$50.97	Waterproofing	All Wet Scuba	04/13/10
Video Controller	$93.23	Lights/Cameras	Amazon.com	04/15/10
LED Lights	$96.83	Lights/Cameras	Luxeon	04/27/10
Cameras	$208.73	Lights/Cameras	SuperCircuits	04/27/10
Batteries and Charger	$174.29	Electrical	Hobby King	04/28/10
PVC	$47.05	Frame	Home Depot	04/29/10
Scorpion Motors (3)	$145.48	Thrusters	Innov8tive Designs	04/30/10
PVC	$32.17	Waterproofing	Ace Hardware	05/19/10
Total Purchases	**$1,943.02**			

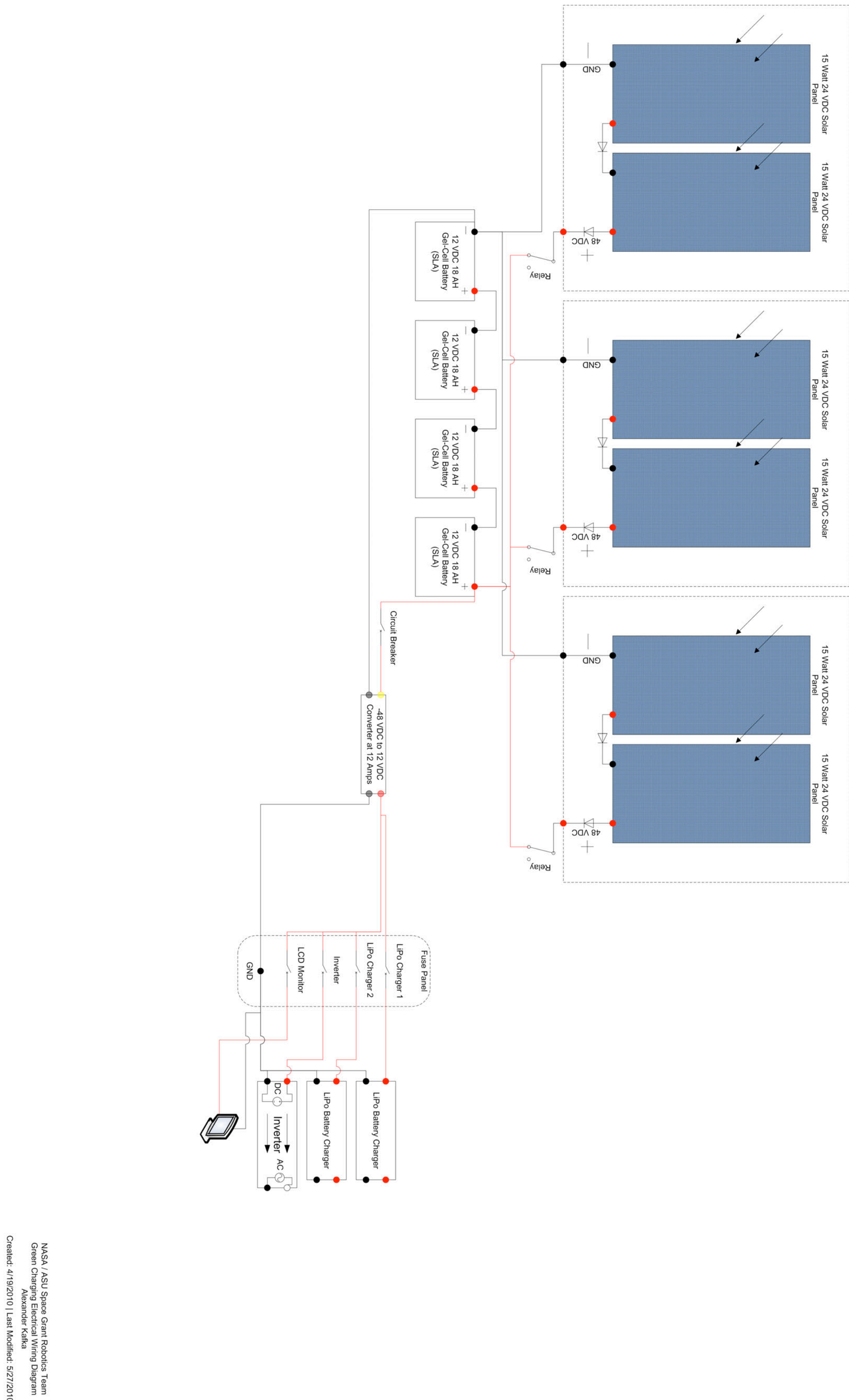
Donations (estimated values)

Description	**Value**	**Category**	**Supplier**
Room Temperature Vulcanizer	$500.00	Waterproofing	3M
SeaBotix Thrusters (5)	$1,250.00	Thrusters	Disbanded ASU Robotics Team
SeaBotix Arm	$2,000.00	Arm	Disbanded ASU Robotics Team
Total Donations	**$3,750.00**		

Appendix B: Electrical Schematic



Appendix C: Green Power Wiring Diagram



Appendix D: Software Flow Chart