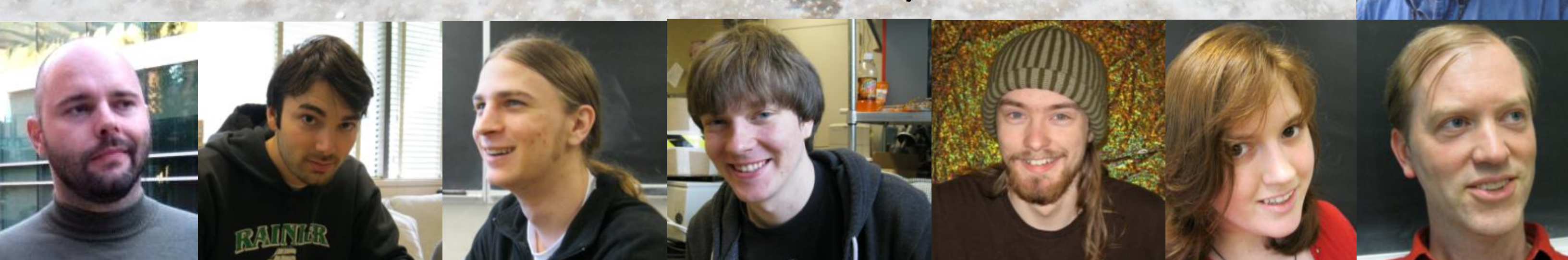
Portland State University

NR Kobi

more metal ~ less plastic



PORTLAND STATE UNIVERSITY ROV TEAM

NR KOBI

UNDERGRAD TEAM:

Arthur Aldrige

CH – Primary Pilot & Fabrication

Patrick Bledsoe

ME – SolidWorks Design & Fabrication

Gregory Haynes

CS & PHY- Programmer

Spencer Krum

CH & PHY – Electronics

Conor O'Connell

EE – Board Design

Kristine Summerfield

PHY – Tech. Report Team Lead

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Keith Parker

EE – Computer Engineering Mentor

Philip Witham

Electrical Systems Mentor

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ABSTRACT:

Undergraduates are developing an underwater remote operated vehicle (UROV) for deployment in scientific missions to hazardous regions of the sea. As an undersea volcano, Lo'ihi, there is a rich terrain full of lava flows and hydrothermal vents that have drawn countless researchers from various sciences to study its unique geography and biology. As such the ROV is designed to be a tool to collect this information and must be extremely versatile as well as being able to overcome a variety of obstacles and difficulties to accomplish specific missions. NR Kobi (our ROV) is expected to do everything from exploration, transporting and setting up equipment, collecting samples of vent temperature, bacteria mats, and crustaceans all in a reasonable amount of time. The hands-on experience in conceptual design, fabrication, and troubleshooting as well and project planning, organization, and teamwork provides a more rounded education that includes training in industry standard software packages. With every step in the process of creating this ROV, new skills are created and current skills refined by the real-world application. Then testing the ROV is simulations is another learning experience in itself, producing results that can also be used to better understand the benefits of certain design choices as well as the limiting ones. The international competition also allows students the opportunity to expand their knowledge and experience of practical applications in physics and engineering plus professional presentations to groups of peers and superiors, as well as connecting them to prospective careers and employers.

REGIONAL TEAM PHOTO (LEFT TO RIGHT) BACK ROW: SolidWorks Design & Fabrication Patrick Bledsoe (Junior), Mentor Keith Parker, Programmer Greg Haynes (Sophomore), Board Designer Conor O'Connell (freshman), Electronics Expert Spencer Krum (Junior), Mentor Phillip Witham, and Faculty Advisor Dr. Erik Sánchez. FRONT ROW: Primary Pilot & Fabrication Arthur Aldridge (Senior), Mentor Jeff Doherty, Tech. Report Team Lead Kristine Summerfield (Senior), and volunteer Georgia Reh.

The Lo'ihi seamount is an active undersea volcano located 30 km from the shore on the southern flank of Mauna Loa with a peak that rests about 909 m below sea level and its height reaches 3,000 m above the seafloor. It is the newest volcano in the Hawaiian-Emperor Seamount Chain and consists of a caldera-like depression 2.8 km wide and 3.7 km long at the summit surrounded by 3 craters. Lo'ihi, like all of the volcanoes in the Hawaiian-Emperor Seamount Chain, is created by a plume of lava that "builds up" the volcano. This seamount has never had an observed eruption but emits frequent earthquake swarms, swarms which have created the surrounding craters. To understand the processes that created the Lo'ihi seamount an introduction to plate theory and hotspots is required.

Plate tectonics details that the Earth's crust is fragmented into dozens of rigid slabs of rock that "float" and move on top of the semisolid asthenosphere (an upper layer of the mantle). Along these plate boundaries earthquakes, volcanoes, mountain ranges, and trenches are predominant (for example the 1,300 km long San-Andres Fault is created by the North American Plates grinding against the Pacific Plate). However, the Lo'ihi seamount and indeed the entire Hawaiian chain were created by volcanic processes nearly 3,200 km from the nearest plate boundary. The theory is that locally long-lasting thermal mantle plumes exist (although not quite sure why) in stationary positions under the plates, and in this case the Hawaiian-Emperor Seamount Chain (see Figure 1) was created by these stationary volcanic processes under the moving Pacific Plate. Said chain includes the current Hawaiian Islands as volcanoes that have passed the hotspot, for example the northernmost island of Kauai (5.5 million years old), to ones currently over said hotspot, the "Big Island" who dates at most 0.7 million years old and still "growing". The theme of this year's competition is the exploration and examination of this growing submarine volcano and surrounding marine life.

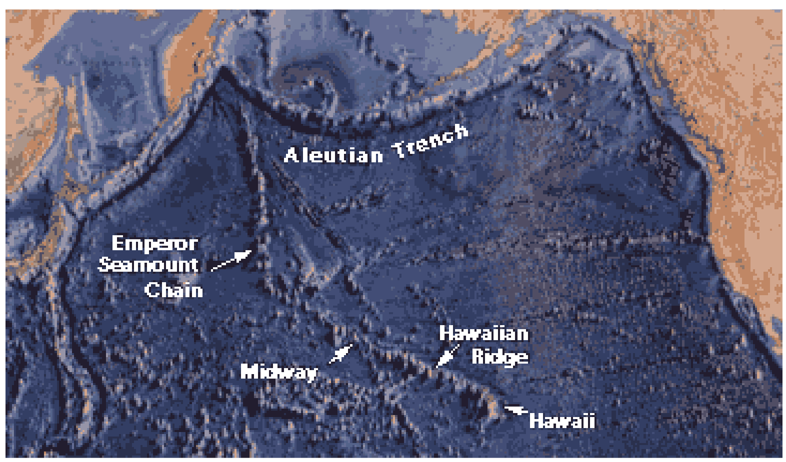

Figure 1: Image of the Hawaiian-Ridge Emperor Seamount chain, over 6,000 km long the trail of this hotspot is composed of more than 80 volcanoes created over the course of 70 million years.

Currently, Lo'ihi is studied and

monitored by the National Oceanic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS) as well as the Hawaii Undersea Geological Observatory (HUGO). The US Coast and Geodetic Survey discovered the seamount in 1940, and it was named Lo'ihi meaning "long", due to its oblong shape, by Kenneth O. Emery in 1955. The benefits of studying the frequency and magnitude of the Lo'ihi seamount earthquake swarms, which typically precede eruptions, could lead to a better understanding of the major eruptions and could also lead to more advanced early warning systems. HUGO has studied the Lo'ihi seamount since October 1997 through a shore station connected by a 47 km fiber optic cable. This cable broke in October 1998, which prompted a repair mission in January 1999 by the Pisces V ROV. The marine life surrounding the area is also a source of intense study, particularly Pele's Pit.

Pele's Pit, one of the three craters surrounding Lo'ihi, contains hydrothermal vents which are a hotbed of biological activity where new species of sea life are constantly emerging. Bacterial mats form around the vents, feeding on the dissolved minerals they emit. Archaea Extremophiles, organisms that thrive in extreme conditions, also form niches near the vents. Archaea play an important role in the carbon and nitrogen cycles and also have important uses in sewage treatment and biotechnology. Studying the bacteria and Archaea may also help to understand the origins of life, since the earliest species of life are thought to have emerged in similar extreme environments. The 2010 Marine Advanced Technology Education Center (MATE) competition consists of four tasks designed to address all of the aforementioned subjects. Each team must build an ROV that can complete these tasks.

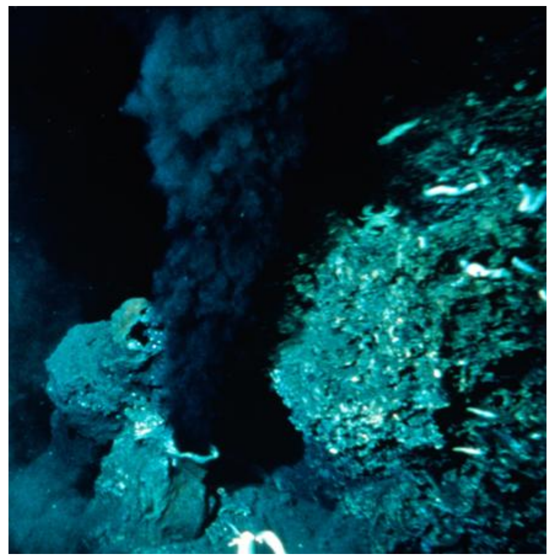

Figure 2: Geothermal vents crop up along the ocean floor near places where magma erupts. As sunlight only penetrates about 300m below the surface leaving the ocean floor a cold and harsh environment, however, vents like this one are surrounded by unusual sea life that thrive around it.

The first task, *Resurrect HUGO,* is to repair HUGO and locate an area of seismic "rumblings". This task includes detecting an area of seismic activity, finding an "elevator" containing a high-rate hydrophone (HRH), releasing the HRH from the elevator, connecting the HRH to HUGO so that it can receive power, and placing the HRH on the area of seismic activity. Task two is *Collecting Samples of a New Species of Crustacean*, the ROV must be maneuvered to the back of a cave, collect up to three samples of the crustacean, and return them to the surface. Task three is called

Sample a New Vent Site; here the ROV must measure the temperature of the vent at three different heights, create a temperature vs. height graph, collect a sample of the vent, and return it to the surface. The final task is to *Collect a Sample of a Bacterial Mat*, approximately 101 – 175 mL of mat, and return the sample to the surface. The Portland State University ROV is designed with all of these tasks in mind. It will include underwater cameras, hydrophones, temperature sensors, sample collection instruments and a retractable arm.

DESIGN RATIONAL:

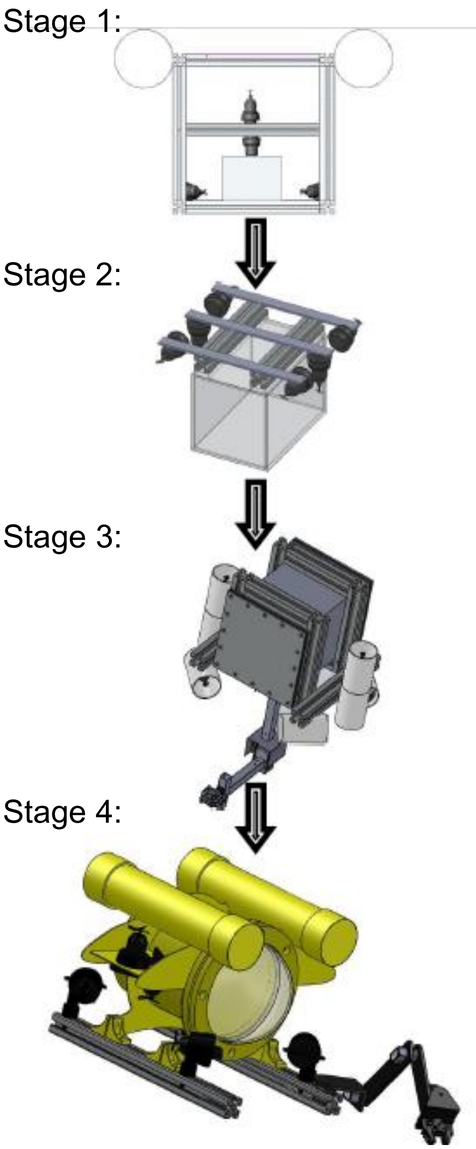

Figure 3: Development of the ROV design flow chart.

The design of the ROV went through several permutations based on the information and materials available to the Team at the time. Initially it was based off the Portland State ROV that was designed last year, except instead of a frame made of polyvinyl chloride (PVC) pipe we wanted to build the frame of extruded aluminum (see Stage 1 in Figure 3). The decision to use the extruded aluminum was made because the slots allowed for the mounting of the motors and any other equipment to be easy and mobile. All the motors were to be positioned at 45° angles to make the velocity vectors easy to calculate and the propellers inside the frame in order to protect them from damage (for example bumping into a wall or damage done in transit). However, during Stage 1 the size of the electronics box used to control the various systems was uncalculated during this initial design time and the Mission Tasks had yet to be released by MATE. Once we were aware of the size of the electronics box (which was already too unwieldy in our initial design) and the Mission Tasks led to the development of Stage 2.

Stage 2 began as a main design in response to Mission Task 2: *Collect Samples of a New Species of Crustacean*. Given the size of the onboard electronics box (which would block the motors and make the rest of the design unstable) and the size of the cave opening (80x80 cm), our original design was far too large to fit in the cave. A Comparison of these two stages of the ROV is shown in the figure right. Stage 2 was a rough look designed mostly for the electronics containment. Here the extruded aluminum was to be mounted directly on the onboard electronics box, which posed another complication later in the design/production process.

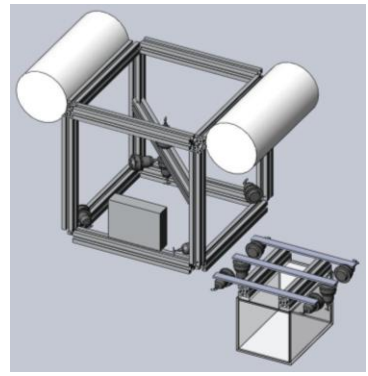

Figure 4: Stage 1 and Stage 2 size comparison.

Further development of the design led to Stage 3. Here the extruded aluminum would be mounted all over the electronics box as a frame in order to accommodate a propulsion system as capable as the original design (for more details see next section) and provide mounting points for the arm, which is a necessary component for all the Mission Tasks. The design also called for a single or double flange in order to make the electronics sealed inside extremely modular. However there were several difficulties with this design, mainly how the extruded aluminum frame was to be mounted on the electronics box. There were two ways they could be mounted; by bolting the extruded aluminum frame to the electronics box or by chemical welding. Both presented different complications, bolting would introduce multiple "breech" points and had to be carefully waterproofed and monitored and the chemical welding would be complex as none of the team had the skill or experience to complete the procedure successfully (a note: the electronics box was also to be constructed with the chemical welding). These problems were dealt with in the next incarnation of our design, Stage 4.

This final, more elegant, design was constructed around a repurposed cryo-pump (that was used in high vacuum down to 10^{-8} Torr) as shown in Figure 3: Stage 4. Furthermore, the inner dimensions of this repurposed pump (diameter 200 mm and depth 230 mm) kept in line with the running theme of easily accessed and removable electronics. The extruded aluminum remained as mounting points for the propellers and the arm, but now served as landing struts as well as protecting the arm from damage (when the arm is fully retracted). Despite the difficulties in milling the cryo-pump to meet our specifications the chamber is an excellent material, strong and surprisingly lightweight. For more information on the individual components of the ROV, please see the next section.

Figure 5: Arthur Aldridge filing away burrs on the waterproof connector holes.

Vehicle Systems:

There are several systems on NR Kobi that require a closer look, and as such this section is broken into subsections. Figure 6 shows a general overview of the entire operational system, for reference. Following are details on the manipulator arm, control system, electrical system, propulsion, and sensory systems.

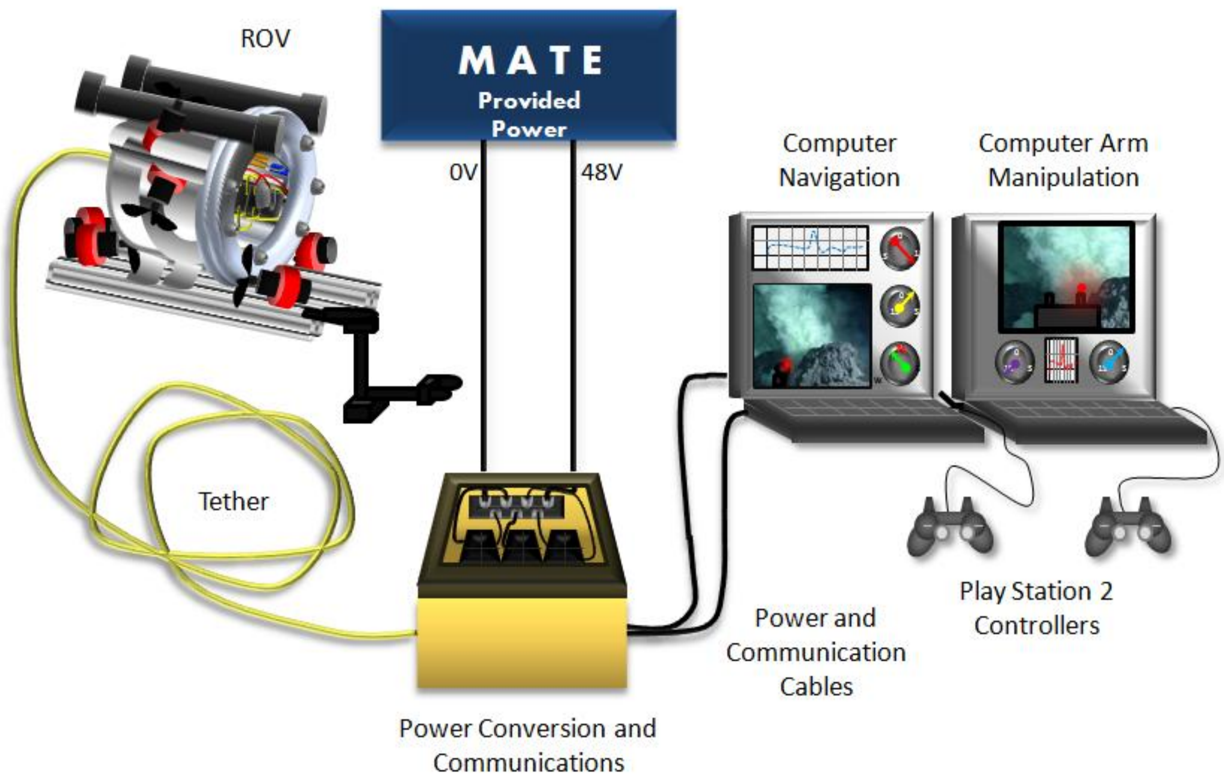

Figure 6: This is an overall general graphic of the entire operational system.

Arm:

The manipulator arm is composed of five high-torque digital servos; one each for the rotator cuff, shoulder, elbow, wrist, and gripper. The four non-gripper servos have 180° of motion with a max torque of 89 oz-in and a max speed of 0.17 sec/60°; all servos are modified to be waterproof (see Challenge Section). The other components are the arm sections (student-machined from sheets of high-density polyethylene) and a gripping device (ordered from Lynxmotion). Its slim design allows it to be tucked away between the ROV landing struts, preventing damage from any accidental collisions during transit to task sites. The arm is mounted on the starboard strut, this allows for the collected samples to be stored in a container attached to the port strut. There is a tradeoff for this minimal design, with only one point of contact at each joint the arm is somewhat fragile. On the opposite strut there is a net for holding all the samples from the crustaceans (3 critters), hydrothermal vent pieces (3 PVC pipes), and the bacterial mat in its collection device (which is essentially a tube held by the arm). The servos are controlled by a Teensy microcontroller housed in the ROV chamber and operated by a Logitech gamepad.

CONTROL SYSTEM:

The ROV software consists of a client, a server, and several microcontroller applications: the client interprets input from the user (via joystick, or mouse) and displays information about the current state of the ROV to the user, the server acts as a proxy between the client and the various hardware devices on the ROV (allowing the client to communicate over a single connection using a variable based protocol), and the microcontroller code talks over a serial connection (over USB) to the server and responds to queries from the server to set or obtain the current state of various hardware devices. The client application is written using C++ and Qt, this toolkit was used due to my [Programmer Greg Haynes] previous experience with this software, its cross-platform abilities, and extensive features. Also the cross-platform abilities of Qt allowed the software to be developed before knowing the specifics of the computer used to control the ROV. This also made sharing the software among team members more feasible than it would have been if our client application were developed in a Windows or Macintosh specific manner. Furthermore, the server application is written in python and uses a simple variable based protocol to allow the client to request the value of or set the value of a variable. These variables can be directly associated with a hardware device, the python server handles communicating with the correct hardware (usually a serial device) when a variable is modified. The microcontrollers speak a binary protocol to set the correct value, or request the current state of various hardware devices.

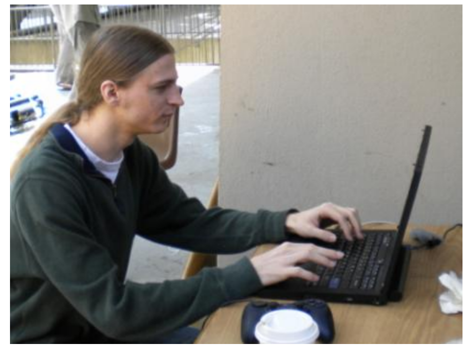

Figure 7: Greg Haynes initiating the ROV startup sequence.

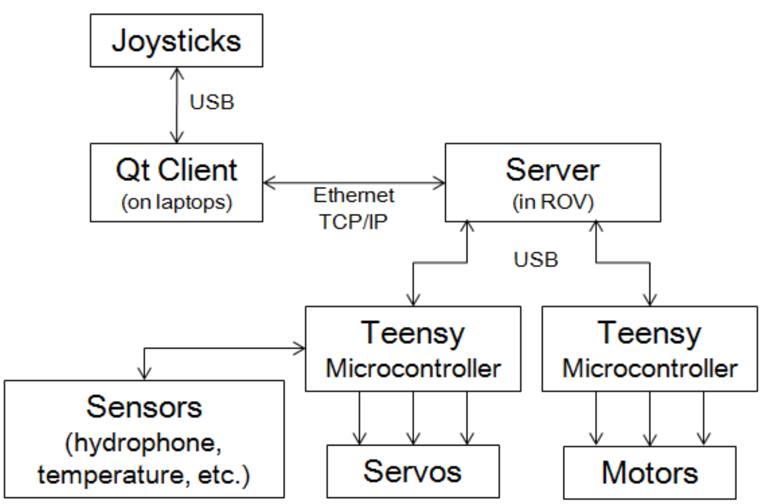

Figure 8: Block-diagram overview of the software system (further diagrams in the Appendix).

ELECTRICAL SYSTEM:

The ROV is shore powered from a 48 VDC supply. We convert this to two floating 12 VDC supplies using three 200 W switching power converter modules. These were built into a splash-proof box with a 25 A circuit breaker on the input power. The two outputs are isolated from the input ground and from each other, and travel through separate lines in the tether cable. One is used for supplying the internal computers, and the other powers the motors and servos. Total output current available is over 40 A, though peak consumption is on the order of 20 A. Input current at 48 V is under 1 A when idle, and peaks at about 5 A with heavy motor use. Motor power is actually redundant, with two modules combined by Schottky diodes. Keeping the power separate prevents the cable voltage drop from the use of the motors from interfering with computer power. From the 12 V supply, power for the Mini-ATX server computer is supplied by a switching converter module located in the ROV.

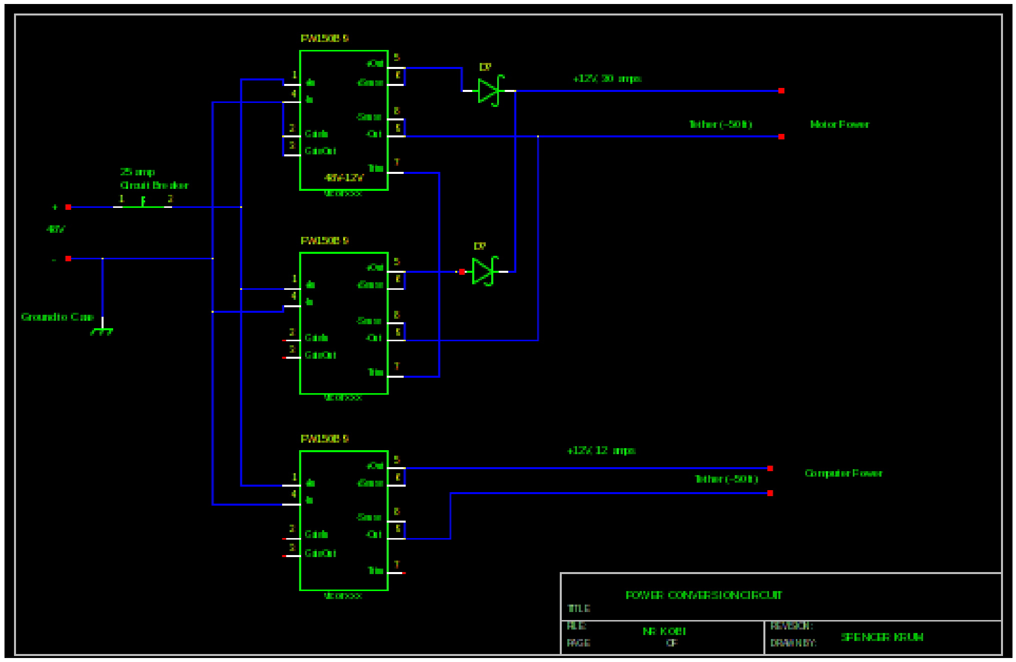

Figure 9: 48V to two 12V Ground Power Converter schematic with circuit breaker, ground isolation in a waterproof box. The Motor Switching Power Controller schematic is shown in the Appendix.

Propulsion motor speed control is done by switching modulation of the 12 V motor power by eight MOSFETs built into the ROV. The PWM signals are generated by an AVR microcontroller ("Teensy++") which accepts commands and power over USB, from the server computer. The switching is in the high audio frequency range and uses the motor's own inductance rather than an output filter. Schottky diodes and a few resistors are the only other parts involved. This was the simplest method we could find, short of spending money on commercial PWM controllers. PWM signals for the arm servos are generated by another "Teensy" microcontroller, which also samples analog sensor signals such as from several temperature sensors.

PROPULSION:

The ROV is equipped with eight bilge pumps, four to control lateral motion and four to control vertical motion. This propulsion scheme calls for firing thrusters in pairs to achieve forward, backward, strafe, zero-point turning, and vertical up/down motion. The propellers are mounted with custom machined adapters and the bilge pumps are capable of handling a max of 12 V and 6 A of power. This setup has made the horizontal extremely versatile, see Figure 10 below, as the potential maneuverability in a small space, for example Mission Task 2: *Collect Samples of a New Species of Crustacean*, like a cave easier to handle. However, there is a limitation in the design as it gives no control whatsoever over pitch, it instead relies on a low center of gravity and a high center of buoyancy to level the vehicle. Nevertheless, it is an extremely effective design, plus it is easy to operate being the familiar PS2 controller.

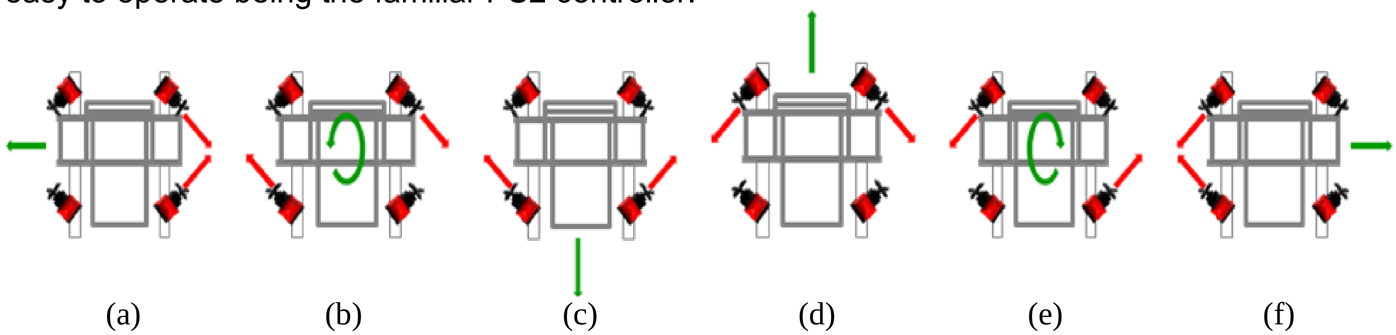

Figure 10: The six horizontal motions as described by the active motors (red arrows) and their direction of motion (green arrows). From left to right they are described as (a) strafe left, (b) zero-point counterclockwise turn, (c) reverse, (d) forward, (e) zero-point clockwise turn, and (f) strafe right.

SENSORY SYSTEMS:

There are a variety of sensory systems integrated into NR Kobi's design: a system of cameras, a hydrophone, and a temperature sensor. The cameras are USB webcams using Video 4 Linux Motion-JPEG encapsulation with 640x480 pixel resolution per frame at 24 frames per second the cameras experience less than 100 μs of latency when tested over a wireless network. There are 3 USB cameras mounted in various positions (two in the main chamber & one on the end of the arm) on the ROV for maximum environmental coverage. Then the hydrophone is mounted on the underside of the ROV so that the ROV may hover above the three prospective sites in Mission Task 1: *Resurrect HUGO*. Thirdly, the temperature sensor is mounted on the grabber of the arm in order for Mission Task: *Sample a New Vent Site*, by mounting it there allows for the precise movements of the servos to maneuver this sensor into the PVC construct. These sensors are integral to the ease of operation of the NR Kobi, and to the success of all four mission tasks set before us.

Figure 11: Jeff Doughty, Spencer Krum, and Conor O'Connell looking over Greg Haynes's shoulder as he tests the Arm.

The process of troubleshooting is essentially a series of steps that vary from problem to problem, however, having a general guide helps focus attention on solving the trouble efficiently. First and foremost, documentation and progress reports are important, because they keep team members up to date on what is being done so that problems are quickly noticed. Next is identifying the problem, which is usually composed of distinguishing symptoms and using specific troubleshooting techniques to specify it (if hardware oscilloscopes and multimeter are perfect for testing individual components, if waterproofing then o-rings and epoxy was the first choice). Once the problem has been found, possible solutions can be considered as well as the possible consequences. Finally when the solution is implemented it too needs to be evaluated to confirm its success. Following this general model is essential in complex projects. By avoiding the guessing game seemingly complex problems become simpler and the complex ones are easier to deal with. From challenges in the available materials to lessons and skills, troubleshooting has played a major part in the success of this project.

CHALLENGES:

One challenge was the fact that the servos were not intended to be waterproof, which was a problem as they were also essential to the design. To waterproof the servos, the Back Plate was glued by epoxy originally marine adhesive sealant was used but the bond between the sealant and the plastic casing kept deteriorated. All four Back Plate screws needed an o-ring around them, there was another o-ring placed in between the gear-cap and main chamber, and finally an o-ring on inside around drive shaft against the gear-cap. Lastly propylene glycol was injected into the chamber because it has a similar density to water (bringing it close to a neutral density) and it is food safe as declared by the Food and Drug Administration (FDA). With this treatment the servos are ideal for the design, yielding precise position control of the arm. Waterproofing was the prevalent challenge in the production stage of the ROV, in both the connectors and front dome.

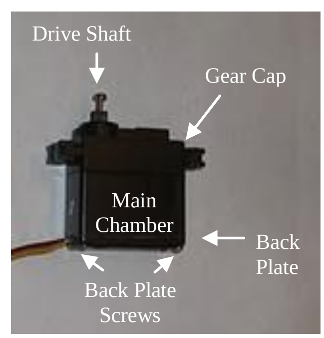

Figure 12: A servo.

The waterproof connectors were intended to have only one cable running through them, not four, none of which had the necessary cable diameter either. But four is what the design called for and a solution had to be found, and while not elegant this constraint was met. To fix this problem shrink-wrap was placed over the bundled wires and filled with Gorilla Glue where then the shrink-wrap was heat-shrunk. By heating the shrink-wrap when the glue had yet to dry the decreasing size compressed the glue through all the empty spaces and eventually out the end of the shrink-wrap tube. This plugged all the places water could seep through the connectors as well as increasing the size of the wires to properly fit in the waterproof connectors. Another waterproofing problem was the dome; the group ordered a transparent half-circle dome with a flat flange to mount on the front of the ROV. However, the product that was received was substandard as the flange was in fact not flat. This led to the dome eventually cracking when bolted onto the ROV; eventually a transparent flat plastic plate was mounted instead.

Figure 13: Patrick Bledsoe waterproofing servos.

LESSONS LEARNED:

One of the biggest difficulties of the project in the process of designing and producing was the team management. This year all decisions were made by democratic votes, with no particular leader to direct focus and demand results. This resulted in confusion of what exactly was being done, who it was being done by, and when it was to be done. As well as the fact that action had to be halted while input from all the members who occasionally were not present at all the meetings. As such, when this topic was brought up to the group it was unanimously agreed that an organized team hierarchy would have been a better idea. The ideal setup would be a president to make the key choices based on the team member's recommendations, a vice president to handle the timeline, a secretary to collect and hold all the documentation, and a treasurer dedicated to all the budget needs. While this system could be considered a future improvement the group likes to think of it as a lesson not easily forgotten, one on the necessity of being able to make key decisions in a manageable amount of time, thus removing the 48-hour deadline rush.

Figure 14: Spencer Krum, Greg Haynes, and Conor O'Connell at a group meeting.

FUTURE IMPROVEMENTS:

Our team would like to see an Inertial Navigation System (INS) implement in the ROV next year. The system would take the existing data from the ROVs accelerometers and gyroscope compiles it and produces the orientation, position, and velocity of the vehicle. The advantage of such a system is that there are no external references needed for the computer to update this information. Such a system would be incredibly valuable on an ROV project like this one, and it is a system that is used in commercial vehicles as well. Speaking of commercial vehicles, another improvement would be to fill the chamber with propylene glycol instead of leaving it full of air. The chemical would increase the depth rating of the vehicle to depths where it would in fact be useful in data collection on the Lo'ihi Seamount but the added difficulties made this particular improvement less than ideal. As part of our design the ROV electronics were made to be fully modular where we would easily be able to remove them completely and replace any damaged or malfunctioning parts very quickly. By adding the propylene glycol to the chamber the ability to remove the electronics and swap out parts becomes a much longer process involving the drying of the electronics and then followed by the cleaning of them before replacing them.

REFLECTIONS:

The team enjoyed working on this project, specifically because it was outside the classroom and applied what we learned in our classes. For example, in our Robotics Support Bay (the Physics Lounge) we were faced with an inductance in the wires on the arm which required us to change its entire scheme, at least we have practice in problem solving. New skills were learned, for example Arthur learned to TIG Weld and Spencer learned to waterproof servos, not to mention the milling that was required. Plus the group learned to use industry standard software (SolidWorks, PCB 123) to design a vehicle to accomplish certain tasks. Followed by the production of said vehicle, the processes themselves were a learning experience designed to test our problem solving abilities, group work, and our ability to reach the target results (in our case building something that works). Overall it was a good experience as an exercise in building, people management, group dynamics, and technical application.

Figure 15: Kristine Summerfield grinding the ROV Chassis.

Budget/Expense Sheet:

	Description	Quantity	Donated amt	Cost
1	Stainless Steel Scrap (cryo-pump & flange)	1	$ 500.00	
2	Stainless Steel Chassis	1 sheet	$ 100.00	
3	Lynxmotion Gripper	1		$ 15.00
4	Bilge Pumps	12	$ 90.00	$ 90.00
5	Propellers	20		$ 180.00
6	Waterproof Connectors	9		$ 289.44
7	Servos (HS-5485HB HS-5465MG, & HS-5485HB)	5		$ 211.79
8	3" ABS Pipe and Endcaps	1 10ft pipe and 4 endcaps		$ 10.00
9	Wire (Ethernet 14gage, 18gage, various)	various	$ 238.00	
10	Aluminum Rod	1	$ 20.00	
11	Cameras	8 (2 donated)	$ 40.00	$ 75.00
12	Hydrophone	1		$ 10.00
13	Temperature Sensor	1		$ 2.50
14	High-Density Polyethylene	1 sheet	$ 38.16	
15	PlayStation 2 Controllers	2	$ 60.00	
16	Plexiglas	1 sheet & 2 domes	$ 20.00	$ 75.00
17	Extruded Aluminum	1	$ 20.00	
18	Glue	various		$ 6.00
19	Heatshrink	various	$ 10.47	
22	Hose Clamps	4		$ 10.00
23	DC to DC Power Converter (48V to 12V)	3	$ 150.00	
24	Splash Resistant Box	1	$ 15.00	
25	Teensy++	2		$ 48.00
26	PCB Boards	2		$ 121.70
27	DC to DC Power Converter (12V to 6V)		$ 50.00	
	Subtotal: ROV		$ 1351.63	$ 1144.43
	Donation/Cost Subtotal: ROV		$ 2496.06	
1	Mission Task Props	various		$ 71.45
2	Pool (15'x48")	1		$ 249.00
3	Pool Treatment	1		$ 26.96
4	Travel	7 people	$ 6500.00	
5	70" Garden Hose	1		$ 19.99
	Donation/Cost Total		$ 7851.63	$ 1511.83
	Total		$ 9363.46	

ACKNOWLEDGEMENTS:

The ROV Team was blessed with sponsors more than willing to assist us achieve a level of excellence by providing their time, money, and even supplies when we needed it. Without their help this project would not have been possible. We would like to thank the following for their generous support:

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Kristopher K. Sims
Stephen Plachta
Sarah Paige
Georgia Reh
Sharr Smith
Max Suman
Jane Bloom

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"Some Power PWM Drivers for Electric DC Motors" Stefan Spännare, Pico Technology Jan. 2002 <http://www.picotech.com/applications/pwm_drivers/#chap8>

"Teensy ++ AT90usb1286" Atmel <http://www.atmel.com/dyn/products/product_card.asp?part_id=3874>

Hardware Sources:

"900 Series Buccaneer" ® Bulgin <http://www.bulgin.co.uk/PDFs/CatNo82/Buccaneer_900Series2005.pdf>

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Miscellaneous:

"Propylene Glycol" Wikipedia <http://en.wikipedia.org/wiki/Propylene_glycol>

Mission Theme Research Sources:

“Loihi” <http://www.soest.hawaii.edu>

“This Dynamic Earth: The Story of Plate Tectonics”
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Programming Sources:

“Linux Shell Scripting Tutorial v1.05r3: A Beginner’s Handbook” Vivek G. Gite © 1999-2002
<http://www.freeos.com/guides/lsst/>

“Qt Reference Documentation” Qt <http://doc.qt.nokia.com/4.6/index.html>

“pySerial Documentation” pySerial <http://pyserial.sourceforge.net/>

“Teensy USB Development Board” PJRC <http://www.pjrc.com/teensy/index.html>

Software Sources:

“Debian/GNU Linux Operating System” Debian <http://www.debian.org/>

“Embedded Debian Project” Debian <http://www.emdebian.org/>

“MJPG-streamer” Tom Stoeveken <http://sourceforge.net/projects/mjpg-streamer/>

“Video for Linux Two API Specification” Michael H Schimek © 2008
<http://v4l2spec.bytesex.org/spec-single/v4l2.html>

APPENDIX:

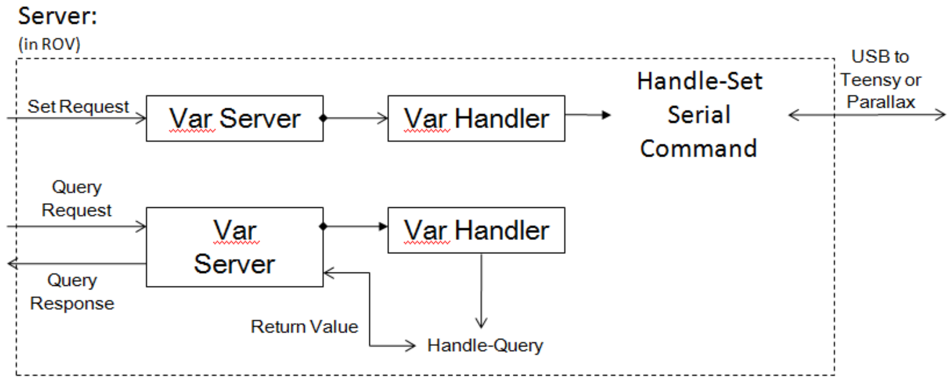

Figure A1: Software diagram of the Server inside the ROV.

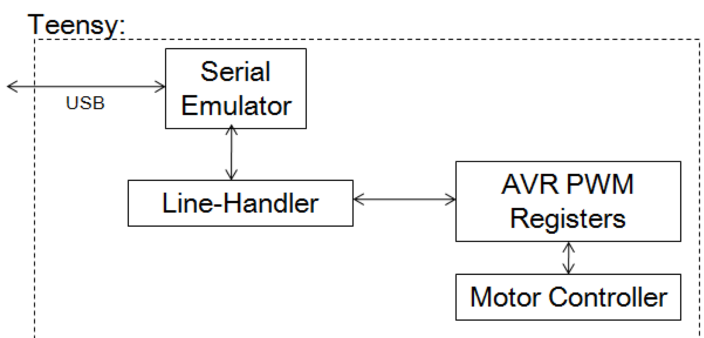

Figure A2: Software diagram of the Teensy operation.

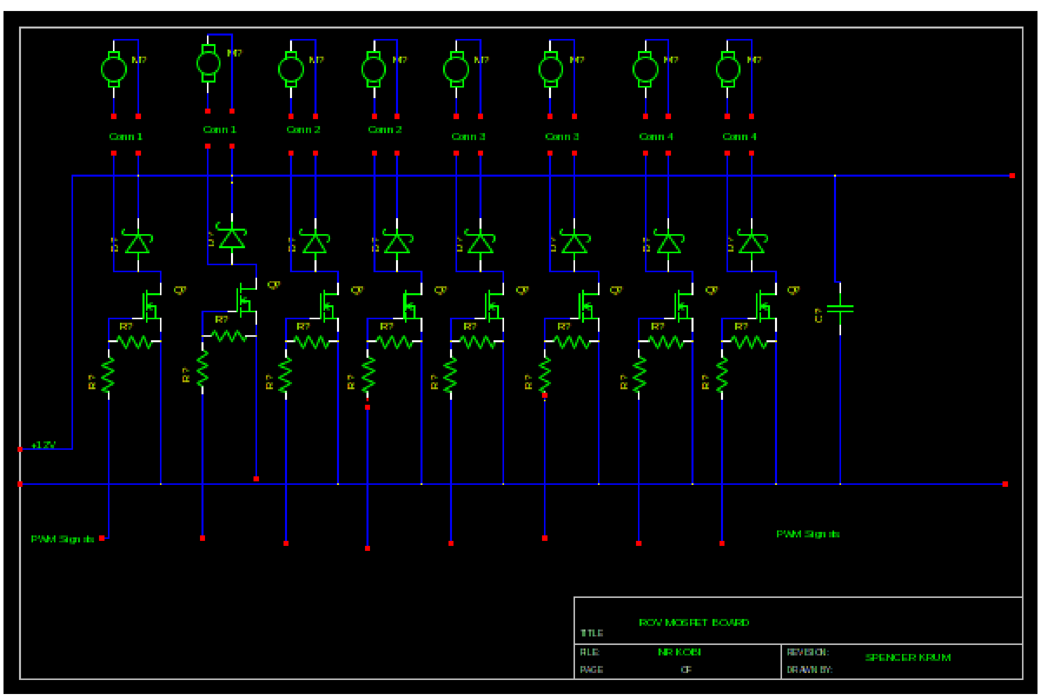

Figure A3: Motor Switching Power Controller schematic.