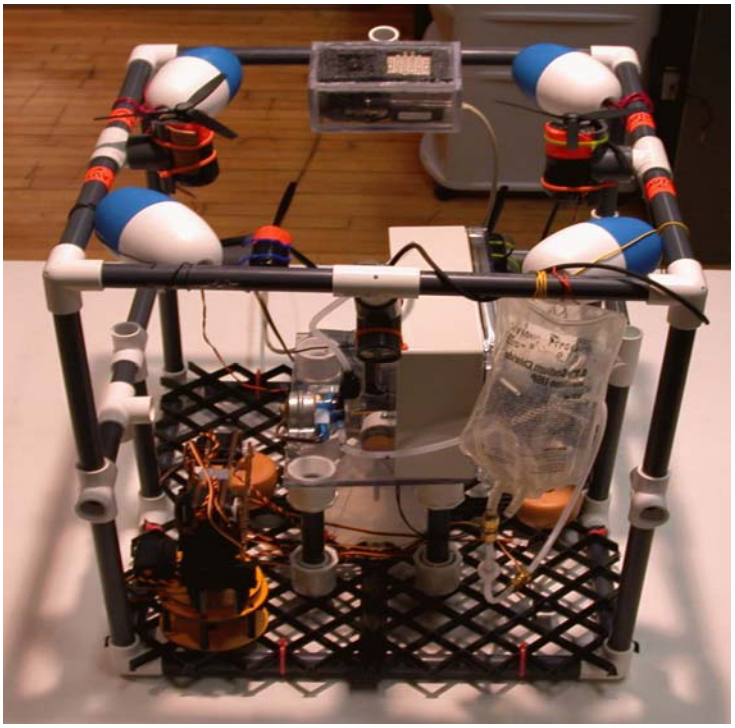
Great Lakes WATER Institute
Wisconsin Aquatic Technology and Environmental Research
UNIVERSITY of WISCONSIN UWMILWAUKEE

University of Wisconsin-Milwaukee
Great Lakes WATER Institute
ROV Team
MATE National ROV Competition
Spring 2005

"PantheROV"



Mentor: Dr. Tom Consi

Team Members	Major	Year
Chris Chudy	Mechanical Engineer	Sophomore
Tim Haagensen	Electrical Engineering	Junior
Mark Marcott	Computer Science	Senior
Greg Oswald	Materials Engineering	Junior
Erik Roedig	Computer Science	Sophomore
Andy Schneider	Computer Science	Sophomore
Joe Traficante	Computer Science	Senior
Korey Verhein	Computer Science and Biology	Junior
Stephen Watts	CS, EE, and Physics	Senior
Josh Zagorski	Electrical Engineering and Physics	Junior

Table of Contents

Abstract

Many things have changed since the UW-Milwaukee ROV team started, but the overall design concept has remained the same: Design a vehicle capable of performing the four required tasks without human intervention. The mission determined the design, while the availability, flexibility, cost, and time determined the materials used. The vehicle's general design is centered around a sampling funnel, which will be used for docking purposes in half of the tasks. A grated floor supports the funnel, which is mounted and centered on the bottom for ease of piloting with a camera view. A One-Wire sensor was added to the sample apparatus for temperature readings. Vertical thrusters were mounted on top and horizontal thrusters in the rear. A robotic arm performs the tasks of establishing communication and the collection of the data probes. The electronics are centered upright in the middle of the vehicle on a platform. The basis of the electronics is a microcontroller, which serves the central functions of vehicle control and data collection. The width of the opening into the pool limited the size and shape of the vehicle, which is in essence a box with thrusters.

Mission Objectives

The goal of our project is to have a remotely operated vehicle that can complete the following tasks; repair a communications link, retrieve items in a drawer, extract fluid from a crevice / natural occurrence, and take the temperature of naturally occurring water vents (1).

Aside from the box design, our vehicle has many interesting features such as our funnel design, liquid storage container, and the stinger. The funnel will be used to guide the ROV onto the thermal vent and crevice. In the case of the crevice, the stinger will be inserted to take the sample. The liquid storage container is a recycled IV bag. Our design includes a custom designed circuit board for the electronics. Our team also incorporated the use of a Rabbit microcontroller to control the PantherROV from the surface (2).

Frame

The frame design is inspired by the Sea Perch (3) that our team built as a gateway into the engineering of underwater vehicles. The vehicle evolved through several designs along the way; all of them had the same general features. A funnel is mounted on the base in the center of the vehicle for simplified docking with the crevice and hydrothermal vent. We needed the length and width to be no more than 50 cm to allow for entrance through the bored “hole in the ice”. This is achieved by placing the motors on the inside of the vehicle. The frame is made up of 12.7 mm (1/2”) PVC pipe with elbow, tee, cross, and other joints for mounting of the motors and cameras. There is a platform in the middle that allows for the mounting of the electronics box as well as the sampling stinger and pump. Neutral buoyancy is accomplished by placing holes in the PVC fittings and allowing water to fill the pipes. Football and donut floats with counter weights were added to provide the correct, slightly positive buoyancy with level trim.

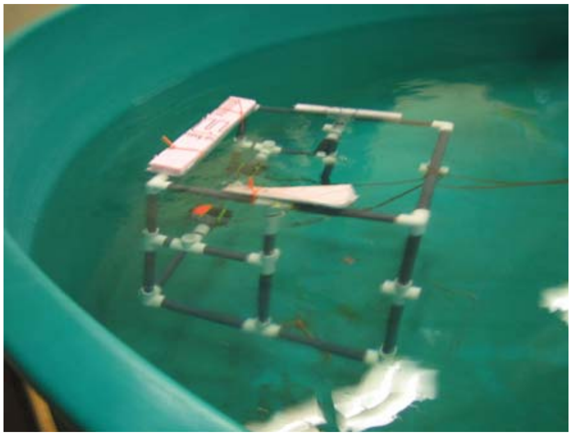


Figure 1: Adjusting the Frame’s Buoyancy and trim.

Propulsion

First, we had to choose how many motors to use. Our inspiration, the Sea Perch, had 3 motors: two for horizontal movement and one for vertical movement. We chose 4 motors for our ROV, placing the vertical thrusters along the edges, which allowed room for mounting the payload in the middle. Next, we decided on 12 V brush motors, because they are a widely used, low cost standard for motors.

The next step was waterproofing, or potting, the motors (Figure 2). This was accomplished by using o-rings, shrink tubing, silicone sealant, Flexane 80, wax, acrylic cement, electrical tape, acrylic nail polish, and rubber end caps.

After the potting process was completed, motor tests were conducted on a test rig with motors strapped to the bottom of a milk crate, using 15.2 cm dual nylon blades secured with setscrews, a Fluke multimeter measured current, and a sealed acid cell provided 13 V. We decided to use the Resources Unlimited motors because they provided the best thrust (~10.27 watts/thruster), as shown in Table 1.

Waterproofed (Potted) ROV Thruster

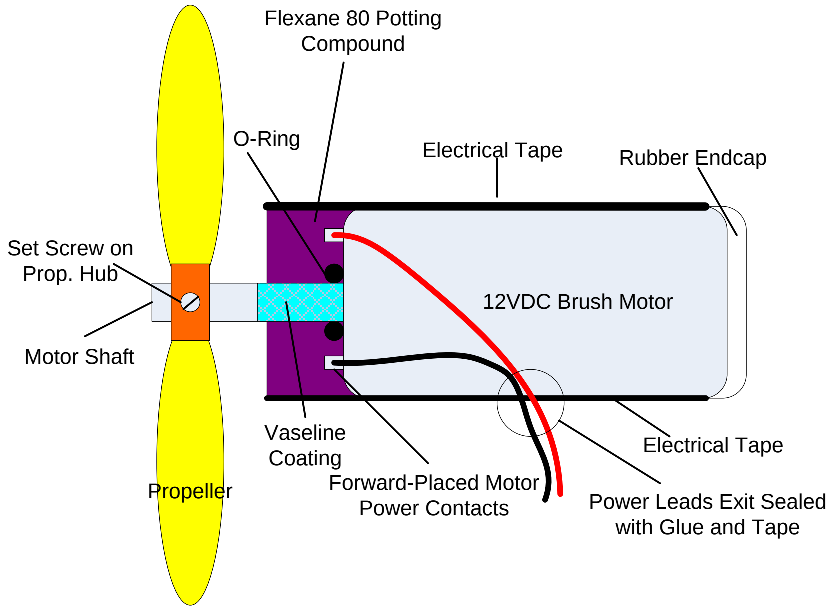


Figure 2: Motor Potting

Motor test

Motor	Current	Result
Rule Bilge pump	1.2A	weak thrust
Bilge pump+prop	4.5A	burned up
Resources Unlimited	0.99A	good thrust
Jameco	13A	high current, burned up
Gear head motor	0.19A	too slow
Wiper motor	---	too heavy, slow, no mounts

Table 1

Propellers were also tested by placing the blades onto a potted motor that was attached to a PVC pipe and the relative thrust was measured by pull and visually inspecting the water displacement. As shown in Table 2, the 15.2 cm three blade prop provided the best thrust.

Propeller Test

Width (cm)	# blades	Material	Result
12.7	2	Nylon	ok thrust
12.7	3	Nylon	good thrust
15.2	2	Nylon	ok thrust
15.2	3	Fiberglass	best thrust
20.3	2	Fiberglass	good thrust

Table 2

Electronics

Once the size of the motors was determined, a maximum power budget was totaled up and a maximum current level was developed. 8.5 A was the initial current budget, the maximum voltage for the motors and the rest of the equipment did not exceed 12 V. To ensure safe operations two fuses were installed; one preceding the DC/DC converter and one at the base of the control board. Both fuses are rated at 9 A which is a half an amp in excess of the maximum current draw. To reduce the voltage to manageable needs, a DC/DC converter was employed to step down the voltage. To supply the needed voltage to the microcontroller and servo controller, the 7805 voltage regulator was used to step down the voltage from 12V to 5 V. To control the motor direction, relays are employed to switch current flow, with the assistance of a low voltage switch. The speed is controlled using pulse width modulation (PWM). The servo controller is connected to six servo motors on the Lynxmotion arm. The control board and the camera multiplexer are contained within a watertight box with internal dimensions of 211.71mm length by 11.71mm width, 70mm depth. The tether contains the Cat-5 cable for video, three 24 AWG lines for laptop to microcontroller communication, two 12 AWG stranded copper wires for power use. Octal buffers (74244s) convert 3.3 V from the microcontroller to 5 V, and then the level shifter converts (ULN2003A) 5 V signals to 12 V. Figure 3 displays the pins utilized on the Rabbit microcontroller.

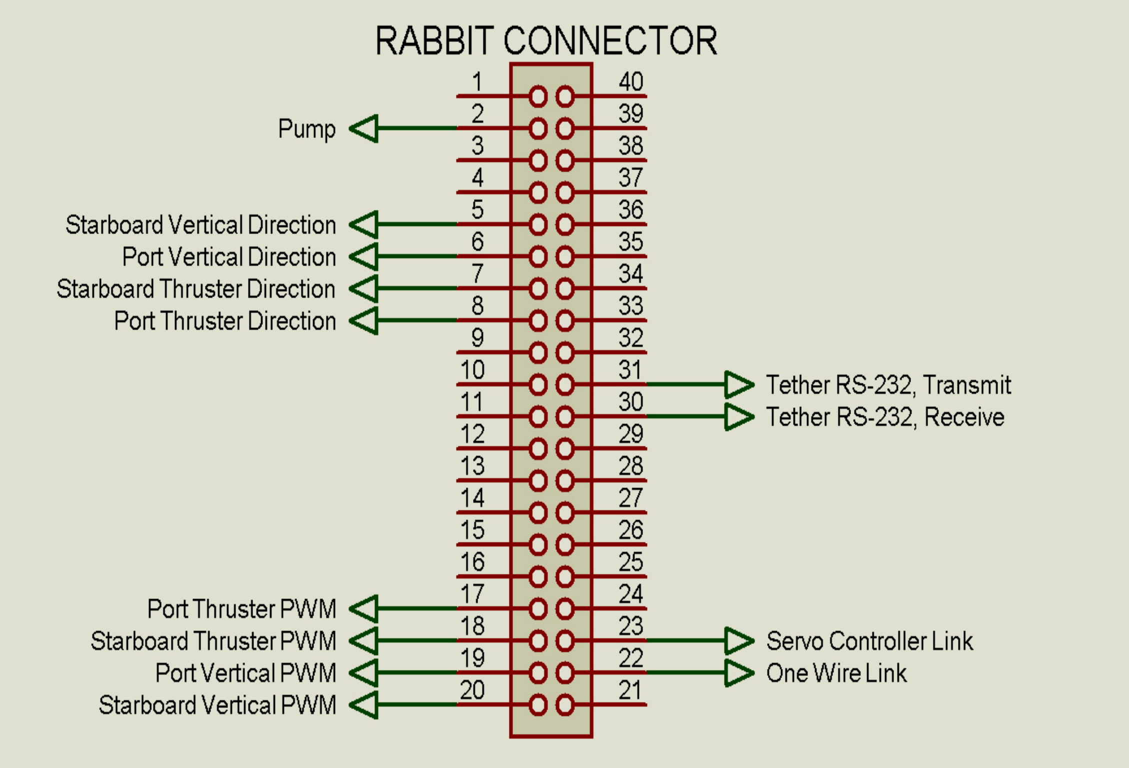


Figure 3: Connection to Rabbit

To use the DC/DC converter on the surface (Figures 4 and 5), we took a hit on the maximum voltage and current. By putting the DC/DC on the surface, we reduced the weight on the vehicle. It also reduced the risk of having the vehicle overheat if this was contained on the vehicle.

The power budget is 8.5 A, which is the sum of the lasers (50 mA), 4 motors (1.2 A), peristaltic pump (2.2 A), stinger motor (1.95 A), and the combination of 3 LED arrays and camera power (0.960 A).

While this may appear to exceed our current power budget the stinger motor and the peristaltic pump are mutually exclusive. Thus the power budget is 7.80 A, not 9.96 A. By using a box with the above dimensions, this increases its heat dissipation capacity allowing the control board to operate without overheating

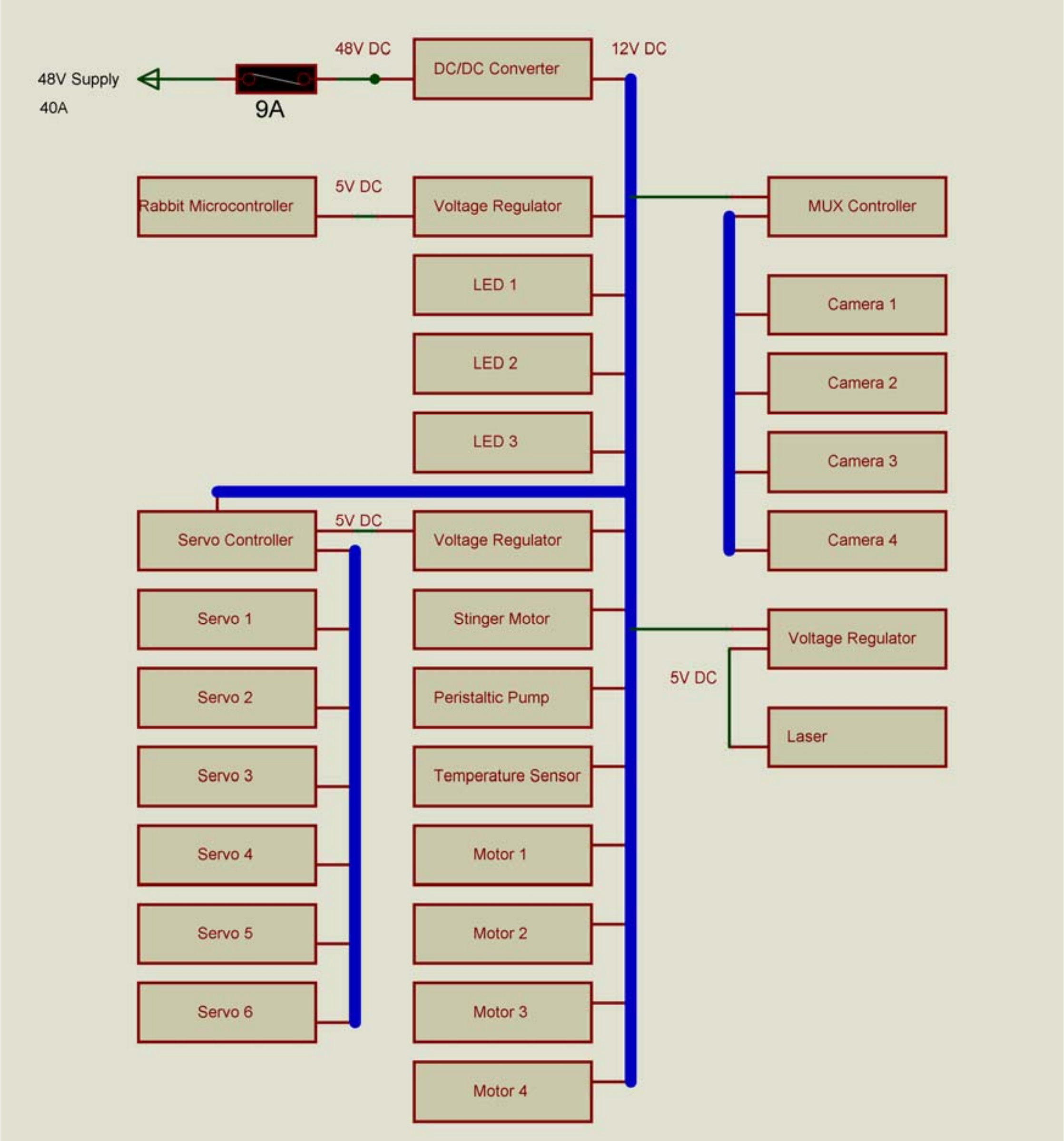


Figure 4: Power Schematic

Electrical Schematics

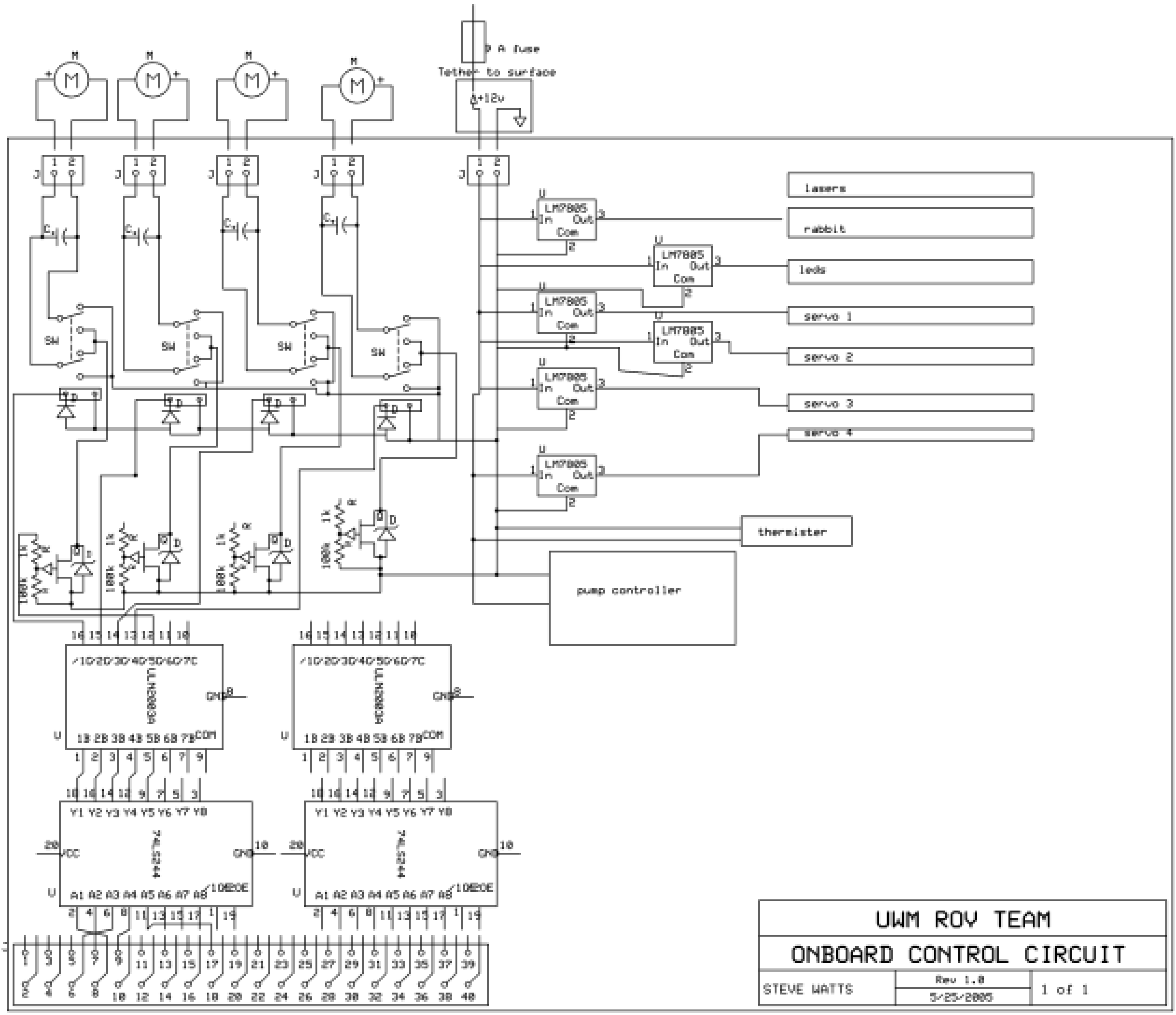


Figure 5: Electronics Schematic

Software and Control

The user interface of our ROV is written in Microsoft Visual Basic, which utilizes a standard keyboard and mouse in order to control the vehicle (Figure 6). The back-end interface, which is located on the vehicle, is a Rabbit Semiconductor RCM3720; Rabbit for short (Figure 7). We designed and wrote code using a PC-interfaced programming language named Dynamic C, which is much like the standard C programming language, but it also includes libraries and keywords that are specific to the Rabbit hardware. The code is compiled and assembled on the PC, and then sent through a serial programming cable to the Rabbit. The process of compiling code on a PC and converting it into something that is understood on a different architecture is referred to as “cross-compiling”.

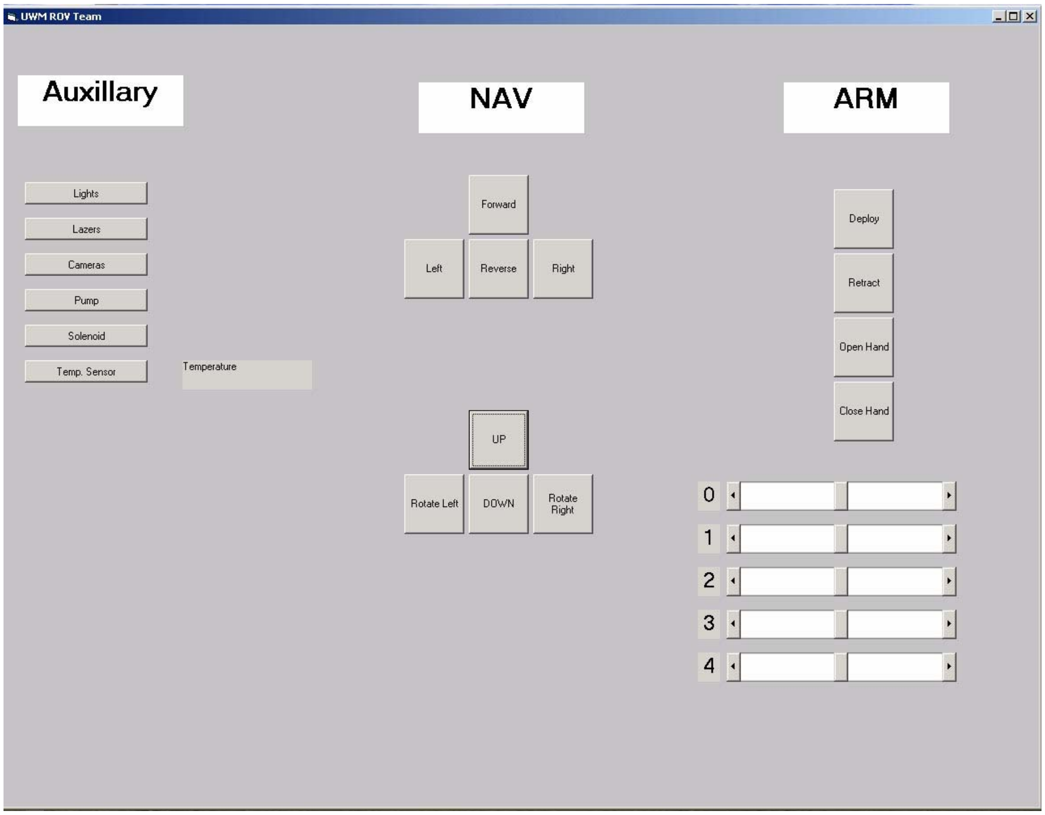


Figure 6: Visual Interface

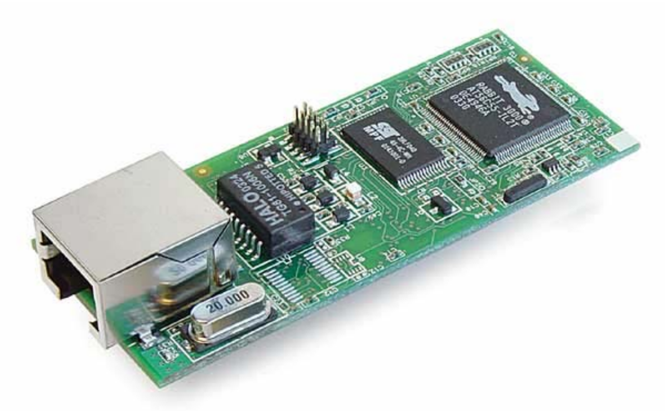


Figure 7: Rabbit Microcontroller

Just like the programming cable used to compile the code, the two interfaces also communicate through a serial cable. The Visual Basic (VB) program is controlled by a laptop, which sends a signal down through the tether to the Rabbit. When a key is pressed on the keyboard, the VB program sends a corresponding array of ASCII characters to the rabbit. Once the array is received, the Rabbit decodes what the command actually means and activates/deactivates the matching hardware (Figure 8). The Rabbit achieves this functionality by executing in an endless loop of receiving commands from its serial connection, decoding what it means through an if-then decision structure, and finally, executing the correct subroutine(s).

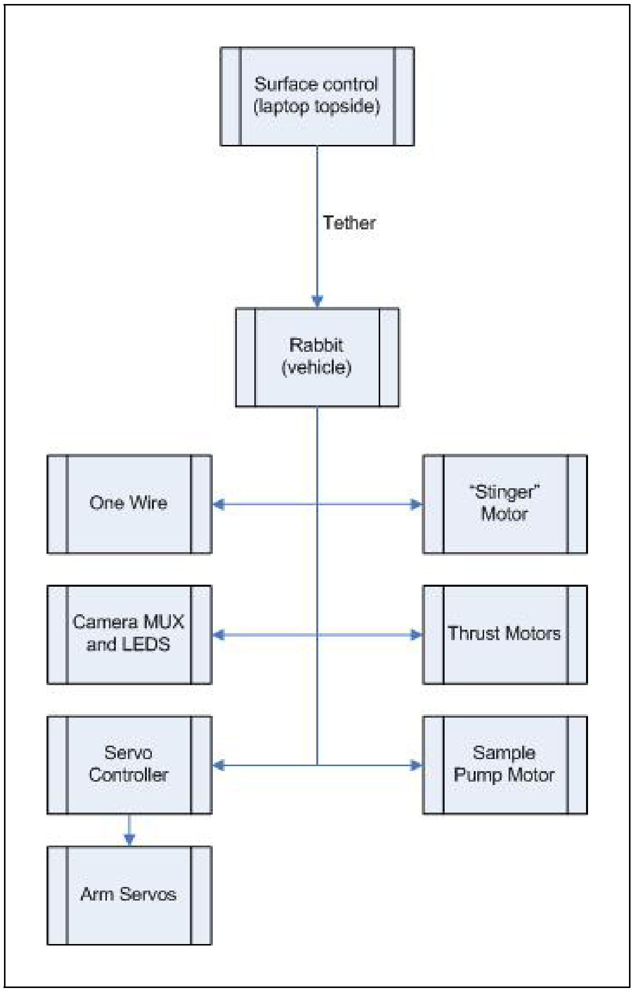


Figure 8: Software and Control Diagram

Video

The main objective of our vision design is centered around two ideas: Minimizing the amount and thickness of the tether running down to the vehicle, and maximizing the amount of area in view at one time in the water. The answer to both of these problems was to feed four concurrent video streams on a single Category 5 network cable from the ROV to the surface and then to split the feeds apart into separate monitors. This solution required us to utilize a video multiplexer on the vehicle, a demultiplexer on the surface, and various video converters from Super Circuits (4) (Figure 9). Besides the advantage of minimizing cable, this particular system allowed us to run inline power to each camera (via each Cat-5 cable), simplifying the wiring requirements on the ROV itself.

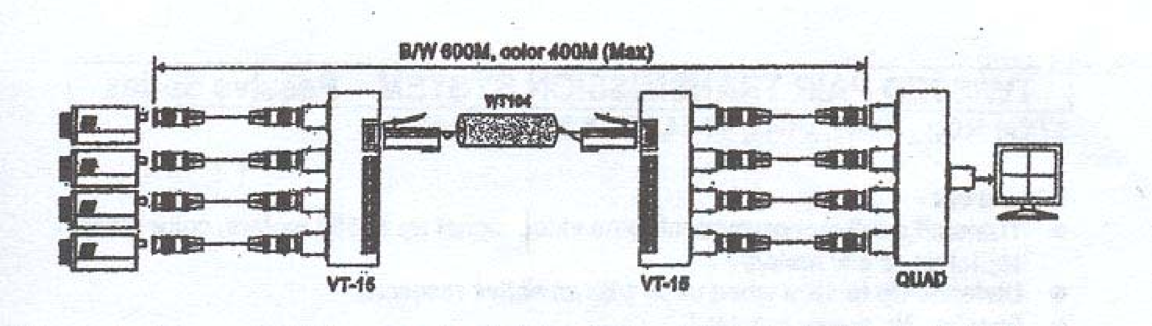


Figure 9: General Camera Design

According to mission requirements, our design must also anticipate reduced lighting underneath the water. In order to account for this, we included a 24 LED light array next to each camera. To protect the camera and the LED array under the water, we enclosed both in a rectangular cube of lexan, which is sealed shut with acrylic cement. A Cat-5 cable, carrying power for each module and the single video stream, exits the box and is sealed with acrylic cement. See Figure 10 and 11.

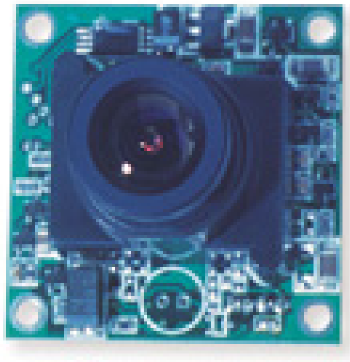


Figure 10: Black and White Camera

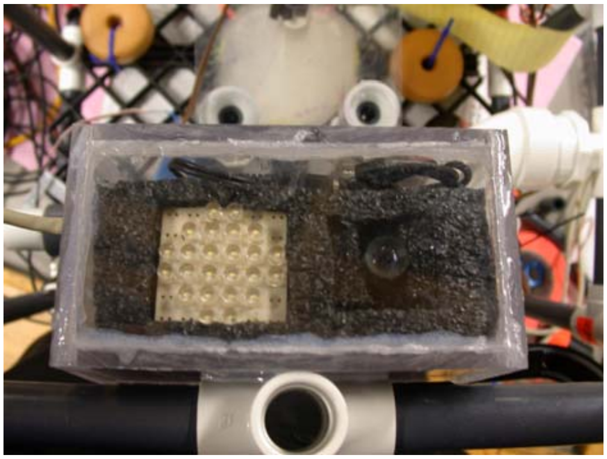


Figure 11: Waterproofed Camera enclosure

Sampler and Cone

In the initial sampler brainstorming sessions, we had to devise a way to take a sample of the “red dense fluid”, as well as take a temperature reading from hydro-thermal vent. Our chosen design is to land on the ½” piece of PVC sticking out of the five gallon pail and the vent container using a funnel as a guide. All further ideas and designs were based around this initial idea. With the ½” piece of PVC already in the center of the funnel, a temperature sensor was placed right at the edge of the funnel to read the venting fluid’s temperature. The next step was to figure out how to get the fluid out of the five gallon pail. In order to extract a sample of the “red dense fluid,” our team decided to inject a small diameter tube into the ½” piece of PVC after the ROV landed on the five gallon pail. The small tube is retracted after the sample had been taken, to allow the vehicle to continue on to the next task. The original idea was to use a Plastruct U-channel or I-beam and small diameter stiff tubing with a rack and pinion gear to lower and raise the tubing. We decided on the Plastruct I-beam and 6.35 mm O.D. aluminum tubing since it fit in the Plastruct I-beam securely. Since we do not know the depth of the red liquid in the crevice, we decided to inject the tubing nine to twelve centimeters deep into the protruding PVC. Using the same principle as the rack and pinion, we decided to use friction to lower and raise the “stinger.” We acquired some rubber stoppers and mounted one to a potted motor. With light pressure the 6.35 mm aluminum tubing slides effectively through the Plastruct I-beam. After this was accomplished we had to formulate a way to pump the liquid out of the five-gallon pail and into our container. We purchased a windshield washer fluid pump as our sampler pump, which we designed the pump process around. The windshield washer pump did not have enough suction to pump the water up through the tubing, so we experimented with priming the pump. With the windshield washer pump properly primed, it pumped approximately one liter per minute, which was very agreeable. Needing to prime the pump can cause a couple of problems; first, our sample would be diluted, and second, we would have to prime it after it was in the water at the competition. We needed a solution that would have enough suction to pump the liquid out with out being primed. Peristaltic pumps (Figure 12) have enough suction and have a bonus feature of pinching the tubing acting like a check valve.

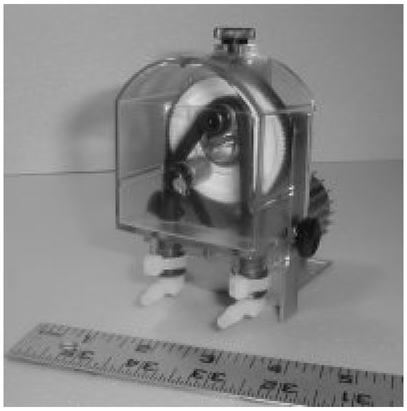


Figure 12: Peristaltic Pump

To waterproof the peristaltic pumps we placed the pump in a box similar to the electronics box with the tubing and wiring coming out of the box. We mounted the stinger and the pump box to a pedastal made of lexan with PVC standoffs positioned over the funnel. We made the pedastal out of lexan so our cameras can see through the lexan to view the stinger, funnel, and container for the red liquid.

The final step in the design of the sampler was to produce a container for the “red dense liquid.” During one of the first design sessions we decided that our container should be a bladder which would be under pressure and empty of any air. It is important that the bladder does not fill up without the pump being activated. Saline bags used for intravenous injections are thick bags which come in many sizes. We acquired a 500mL saline bag and fitted it with a 6.35 mm check valve to keep the bag vacuumed out initially and keep the “red dense liquid” in after we finish taking the sample. This configuration is also modular, it allows us to disconnect the saline bag with the check valve quickly, when we surface after the mission is accomplished.

Aside from the 6.35 mm O.D. aluminum tubing for the stinger, all other tubing was 6.35 mm O.D. plastic tubing. This tubing was thick walled to handle the pressure but flexable enough to move up and down with the stinger. The tubing was interconnected by 6.35 mm brass compression fittings (Figure 13).

The temperature sensor was the last aspect designed for the sampler. Originally, our temperature sensor was going to consist of a thermistor in a voltage divider circuit connected to an A/D converter. Running short on time, for implementing it and then calibrating it, in conjunction with discovering one-wire temperature sensors, we decided to switch to one-wire devices.

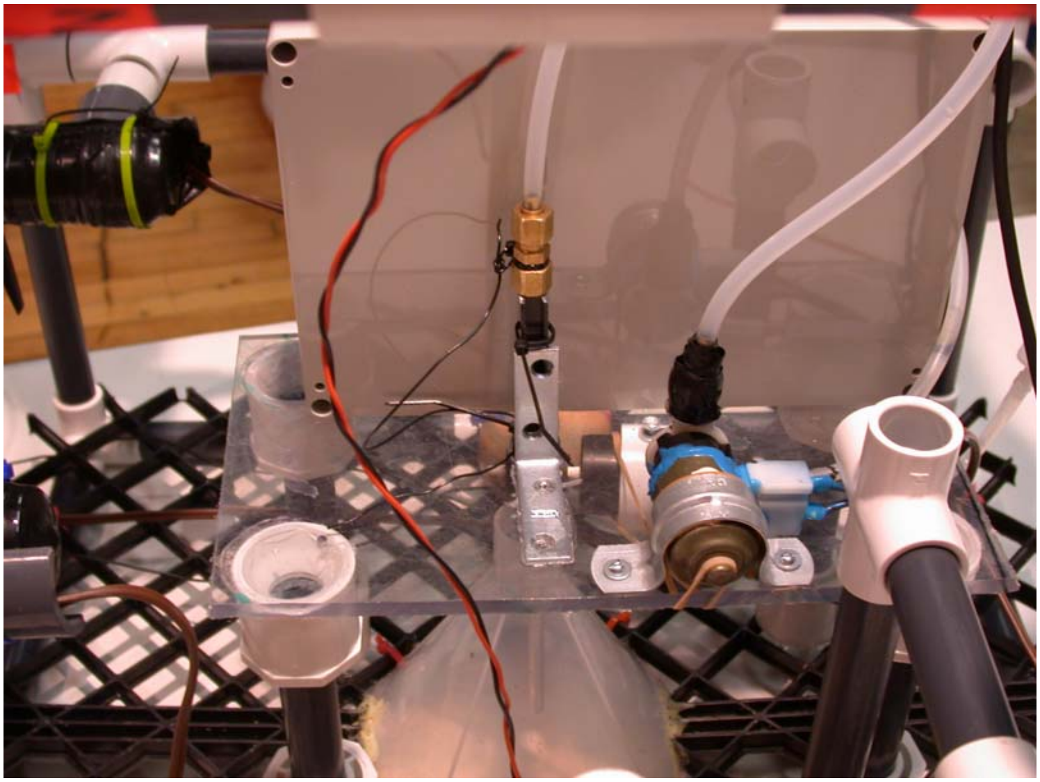


Figure 13: Sampler

Arm

The main objective of the robotic arm is to have an arm that can handle and manipulate the objects mentioned in the task requirements. We opted for a four-jointed robotic arm with a gripper at the end (Figure 14). Each joint is controlled by an RC servo motor and the servo motors themselves are centrally controlled by a servo controller (Mini SSC2) (5). The programming and synchronization of the arm and gripper is achieved by commands sent from the Rabbit to the servo controller.

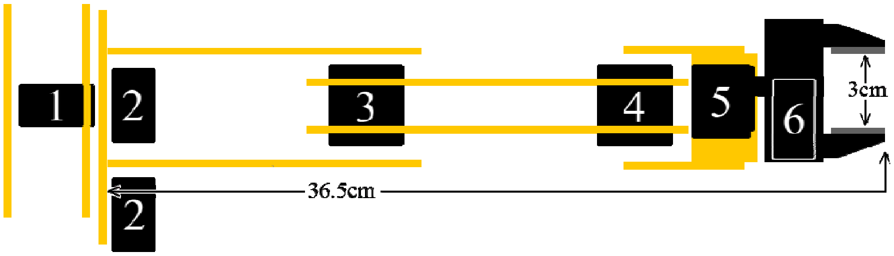


Figure 14: Arm Layout

The desired implementation of the arm focused on ease of assembly, standardized components (to reduce construction time), and easily controllable movement.
The initial idea was to fabricate the entire arm and gripper from scratch. Hand drawings would be manually adapted for Computer Aided Design and Manufacturing software and cut out using a milling machine. The claw was to be constructed of machined aluminum with two cams operating in parallel.
Eventually, we realized that we couldn't efficiently complete this design, and instead, we opted for an arm and gripper (Figure 15) designed by Lynxmotion, Inc (6). This design offered a robust and versatile solution while keeping our engineering requirements simple. The arm consists of 3 mm thick polycarbonate that is easy to manipulate while providing sufficient durability. Laser cut plastic sheets serve as the frame for the entire arm. Standard RC servos are nested in the joints to provide movement.

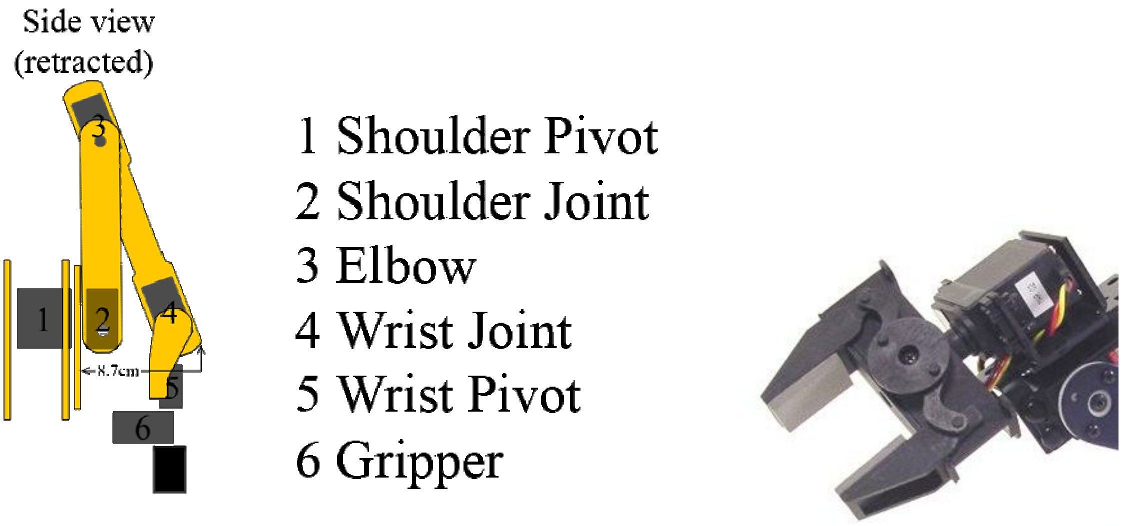


Figure 15: Arm Components

To waterproof the servos, we potted them with Loctite Color Guard (a useful sealant usually used for hardware tool handles) and an o-ring coated with silicone lubricant around the output shaft to prevent water from entering the electronic portion of the servo. Testing proved that this method was effective when the arm was operating in submerged water.

Future Improvements

Propulsion

Our current propulsion system doesn't include cowling, which could improve the amount of thrust produced by our current motors. If we were to include such a design, along with more powerful motors, our vehicle would perform much faster.

Software and Control

A more user-friendly interface could definitely improve the look and feel of our controls. Our current interface involves a keyboard and a mouse to control the ROV, but there is much left to be desired. A joystick or video game pad would definitely improve ergonomics, and possibly create an easier vehicle to maneuver. Force-feedback could also create a more *realistic* feel.

Video

While under the water, it becomes increasingly more difficult to tell how far objects are away. To solve this problem, additional add-ons to the vehicle could be useful. The first add-on would be an attached RC servo to one of the watertight video enclosures. This servo motor is then linked to the Rabbit and can be controlled from the surface. With a push of a button we are able to rotate the camera a full 180 degrees to look down, forward, or upward. The other feature would be adding lasers to the ROV. There are two lasers pointing forward and two lasers pointing down. These lasers would be aligned so that when one is within a certain distance of the object, the two lasers will meet together. With these two additions, it makes it much easier to navigate the ROV successfully.

Arm

The range of motion in our robotic arm is limited to the minimum degrees of motion needed to achieve our tasks. To make a more general, more capable arm, we could extend the degrees of motion by implementing a rotating base and including another servo in our arm to create side-to-side motion.

ROV Technology

One of our goals in the mission to Europa is similar to that of monitoring porewater and hydrothermal vents on Earth. The Great Lakes WATER Institute (7) sent scientists to Yellowstone to study the hydrothermal vents there. Using an ROV, one of the goals in Yellowstone Lake was to monitor the temperature and composition of vents that can be less than 5 m apart. This is important because, "The interactions of the geothermal systems with biology have an important role in the understanding the processes on the origins of early life. The high temperature systems may be relevant to understanding extreme environments on Earth as well as other planets and moons in our Solar System."(8)

Another similar ROV is the ROPOS (remotely operated platform for ocean science) ROV. The ROPOS is similar in design insofar as that both PantherROV and ROPOS are tethered vehicles. Tethered ROVs are generally more practical in that they have virtually unlimited runtime, do not require slow acoustic communication links, and, unless the tether is damaged, only need to come to the surface in order to offload samples. Both ROPOS and our ROV have cameras on the unit, which allow the operator to detect visible phenomena (thermal variation, oil leaks, fish attacking the ROV, etc). Cameras are also used for monitoring the existing sea life near thermal vents, as it usually differs from the colder, surrounding areas. The ROPOS also has push cores (sampling tubes to take loose material samples), a high resolution still camera, and both share a color video camera (9).

Lessons Learned

The main skills that we acquired during the process of building the PantherROV include a better understanding of organization, planning, design and communication. Throughout the semester, we had issues working in the time frame required. We knew that if our current trend continued we would never make it to the competition. Early organization and planning would definitely have solved this dilemma. We also discovered that it is extremely difficult to coordinate schedules between ten or more students, let alone communicate efficiently. Our plan for next year is to incorporate a personal online forum where team members can exchange design and implementation ideas.

Challenge

The main challenge we ran into on our team was not having as much time as we would have liked. Our team was created just before winter break of 2004. The majority of time before break was used to brainstorm and dream up a vehicle to complete the challenge. The next semester we recruited many new members and created teams for each section of the vehicle. Even with the influx of new recruits, we still had trouble making progress. Weeks went by, and there was no physical vehicle to work with; just many ideas and parts lying around. Everyone on the team was getting disenchanted with the project because nothing was getting done. One Wednesday meeting, the project manager made a decision: no more brainstorming, we need a vehicle frame in the water with motors by the end of the meeting. The mission was accomplished and there was a frame moving forward and backwards in the tank. From that point forward the group of students, became a cohesive team and hit the ground running. The vehicle began to take shape and all the parts, from propulsion to electronics, seemed to fall into place. We overcame our challenge by becoming a working, cohesive team.

Acknowledgements

Great Lakes WATER Institute (GLWI)
Dr. J Val Klump – Director and Senior Scientist of GLWI
Dr. Robert Paddock – Researcher at GLWI
Dr. Harvey Bootsma – Assistant Scientist at GLWI
Greg Barske – Machinist at GLWI
Randy Metzger – Machinist at GLWI

Student Helpers:
Paul Baierl
Kyle Beutin
Brandon Blatter
Matt Brien
Matt Henriksen
Amina Tugan
Chris Jetton
Dan Kiedrowski
Daniel McGowan
Troy Thomson
Hans Woehlck

References

(1) Explorer Mission Task Specifications
Marine Advanced Technology Education Center
http://www.marinetech.org/rov_competition/2005/Mission_Task_Specs_FINAL.pdf

(2) Rabbit Semiconductor Inc.
2932 Spafford Street
Davis, California 95616 USA
(530) 757-8400
http:/www.rabbitsemiconductor.com/

(3) Yellow Sea Perch
Build Your Own Underwater Robot
By Harry Bohm and Vickie Jensen
1997, Westcost Words., Vancouver, BC, Canada.
http://imarine.mit.edu/iseaclassroom/seaperch/imanual/html/index.html

(4) SuperCircuits Inc.
One SuperCircuits Plaza
Liberty Hill, Texas 78642
(800) 335-9777
http://www.supercircuits.com/

(5) Scott Edwards Electronics Inc.
1939 S. Frontage Road, Suite F
Sierra Vista, AZ 85635 USA
(520) 459-4802
http://www.seetron.com/

(6) Lynxmotion Inc.
PO Box 818
Pekin, IL 61555-0818
(866) 512-1024
http://www.lynxmotion.com/

(7) Great Lakes WATER Institute
University of Wisconsin-Milwaukee
600 East Greenfield Avenue
Milwaukee, Wisconsin 53204
(414) 382-1700
http://www.uwm.edu/Dept/GLWI/

(8) Aguilar, C., Cuhel, R., and D. Lovalvo. 1999. Pore Water, Vent Water and Ground Water Inputs to Geothermally-Active Yellowstone Lake, Wyoming. ASLO Meeting, Santa Fe, February 1999.
http://www.uwm.edu/Dept/GLWI/yellowstone/pwYNP02.htm

(9) Bill Chadwick
Oregon State University
NOAA Vents Program
http://oceanexplorer.noaa.gov/explorations/04fire/background/rov/rov.html

Budget

UWM ROV Team Expenditures

Description	**Vendor**	**Quantity**	**Unit Price**	**Cost**
Bilge Pumps	Aquatic Eco-Systems	5	$26.44	$132.20
Bilge Pump Parts	Aquatic Eco-Systems	1	$114.50	$114.50
2 oz. Lead Sinkers	Bass Pro Shops	15	$2.99	$44.85
Red Laser Module	Beam of Light Technologies	10	$6.50	$65.00
Check Valves	Cole-Parmer	3	$4.80	$14.40
Funnels (4 Pack)	Cole-Parmer	1	$17.10	$17.10
Vacuum Grease	Cole-Parmer	1	$21.25	$21.25
BNC/RCA Adapter	COM Cables	4	$3.90	$15.60
Mosfets	Digi-Key	20	$1.17	$23.40
Peristaltic Pump	Gleylor	1	$64.50	$64.50
PVC Pipe/Couplings	Grainger	1	$96.47	$96.47
Asst. Wire and Connectors	Jameco	1	$21.00	$21.00
Relays	Jameco	10	$2.28	$22.80
Printed Circuit Boards	Jameco	2	$14.99	$29.98
DC/DC Converter	Jameco	2	$63.95	$127.90
Test Motor 13.5V/13A	Jameco	2	$5.95	$11.90
Electronic Components	Jameco	1	$20.00	$20.00
Misc. Hardware	Local	1	$147.86	$147.86
Robotic Arm	Lynxmotion	1	$224.95	$224.95
Lexan Sheets (3 pack)	Lynxmotion	2	$15.00	$30.00
Test Gear Motor	Lynxmotion	2	$12.00	$24.00
Servo Controller	Lynxmotion	1	$43.95	$43.95
Gripper	Lynxmotion	1	$45.00	$45.00
PVC Pipe/Couplings	McMaster-Carr	1	$125.80	$125.80
Electronics Box	Newark	1	$24.00	$24.00
Rabbit Development Kit	Rabbit Semiconductor	1	$99.95	$99.95
Thruster Motors	Resources Unlimited	8	$2.50	$20.00
LED Array	Super Bright LEDs	3	$14.95	$44.85
6" Video Monitor	Super Circuits	3	$59.95	$179.85
Video Camera	Super Circuits	3	$29.95	$89.85
4X Video Multiplexer	Super Circuits	1	$34.95	$34.95
4X Video Demultiplexer	Super Circuits	1	$39.95	$39.95
Video Transceiver	Super Circuits	4	$24.95	$99.80
40-Pin Breadboard Adapter	Technological Arts	1	$9.00	$9.00
3-Blade Propeller 6x4	Tower Hobbies	6	$3.79	$22.74
RC Servo (3-Pack)	Tower Hobbies	3	$25.97	$77.91
Testing Propellers	Tower Hobbies	1	$20.33	$20.33
			Total	$2,247.59