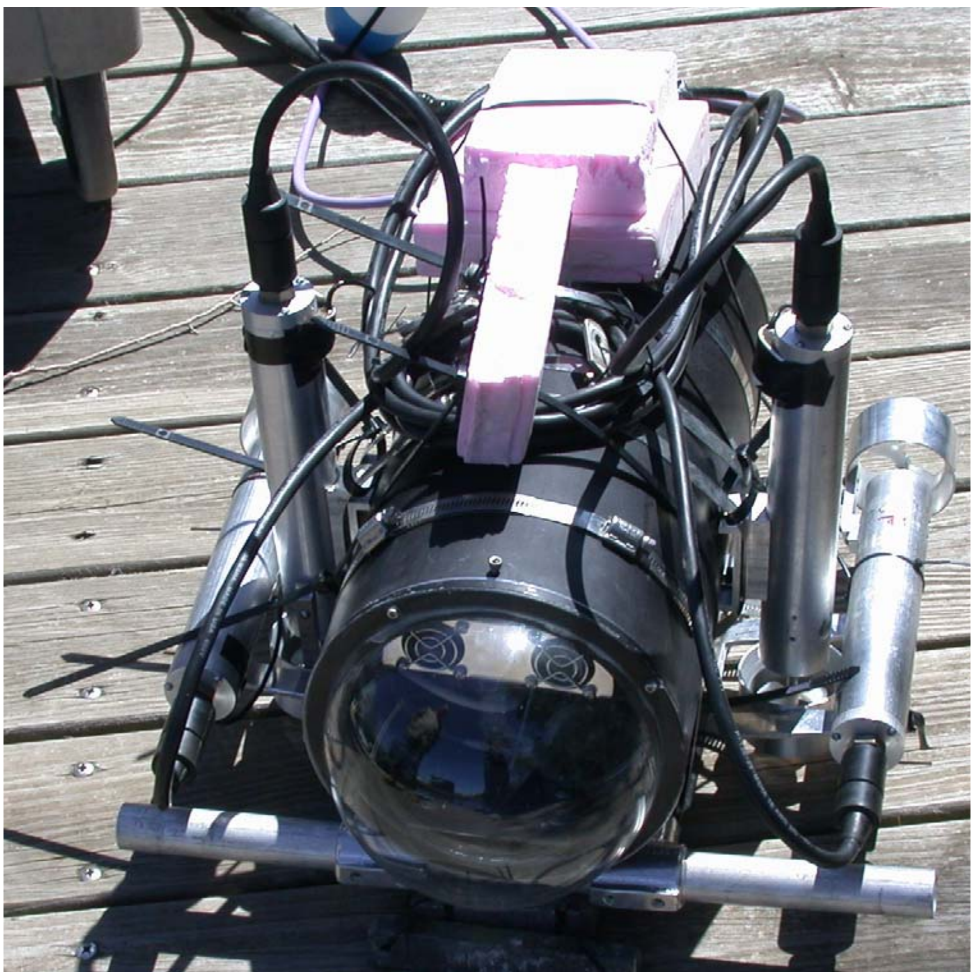
PantheROV IV

University of Wisconsin – Milwaukee



MATE International ROV Competition – June 2008

Mentor: Dr. Tom Consi

Team Member	Major	Year	Expected Graduation
Gregory Oswald	Materials Engineering	Senior	May 2008
Trevin Erdman	Electrical Engineering	Sophmore	Dec 2010
Sam Bingham	Computer Science	Sophmore	Dec 2010
Dave Bogdan	Civil Engineering	Senior	May 2008
John Ringstad	Mechanical Engineering	Junior	May 2009
Mark Matson	Mechanical Engineering	Junior	May 2009

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Abstract

The goal of this project is to engineer a Remotely Operated Vehicle (ROV) to compete in the 2008 MATE International ROV competition. The vehicle is designed to operate in a simulated mid-oceanic ridge environment, completing tasks that a research ROV may have to perform. The first task is freeing a semi-buried Ocean Bottom Seismometer (OBS) from solidified lava. Then samples of the lava are to be collected for future study. Finally the temperature of a hydrothermal vent is to be measured.

PantheROV IV is a major redesign of its predecessor PantheROV III, which competed in the 2007 MATE competition. The major goals were to design a vehicle that was lighter, smaller and more powerful in order to eliminate the mobility problems that plagued PantheROV III. PantheROV IV is roughly 12 kg lighter because of a shortened pressure hull, less frame work, and smaller thruster housings. The vehicle is ~20 cm shorter and 10 cm narrower than previously. The power of the thrusters is increased by 2x due to highly efficient geared brushless motors and high power motor controllers.

The system is controlled by a Rabbit microcontroller "speaking" to a 32 channel servo controller, allowing easy and reliable control of the vehicle from the top-side control computer. The vision for the vehicle consists of three external Ethernet cameras, as well as one internal pan/tilt camera. Object manipulation is performed by a simple gripper mounted to the front of the vehicle. A temperature probe is also mounted to the front of the vehicle.

Vehicle Design Rational

Hull and Frame:

PantheROV IV is designed with superior corrosion resistant alloys and anodized for further protection. The frame is built using 2.54cm IPS T-6063 aluminum alloy pipe. Speed Rail fittings made from 535 aluminum alloy, one of the most corrosion resistant aluminum alloys, are used as interconnects. Tees, elbows, and double side outlet crosses are needed to create the frame. All of these parts, especially the double side outlet cross, provide modularity and flexibility in mounting external equipment such as cameras, lighting, and thrusters. However, minimal amounts of framing were used to reduce the overall size and weight of the vehicle.

The hull of PantheROV IV is a 203.2mm OD, 6.35mm wall thickness anodized aluminum pipe. There are two anodized aluminum end-caps with single o-ring seals. The front end-cap has a silicon sealed acrylic dome for the main pan and tilt camera. Three Impulse bulkheads are mounted on the back end-cap. A 3-ring internal frame with an ABS plastic shelf attached centrally allows internal components to be mounted securely.

The vertical thrusters are mounted directly to the pressure hull using stainless steel hose clamps, while the horizontal thrusters are mounted to an aluminum plate which is attached to the tubular frame.

Thrusters:

The goal was to design a small, compact, lightweight thruster to be mounted on PantheROV IV. Aluminum was chosen for the construction of the thruster's pressure can because of its light weight and its availablility The motors which drive the vehicles are Astroflight 801PM-8T Micro Planetary Motors. These motors are brushless motors which have a 4 to 1 gear box attached. They results in high torque while maintaining very small size. The brushless motors also have an advantage in efficiency when compared to standard brushed DC motors (1).

The thruster consists of an aluminum tube (4.44cm in diameter) which serves as a pressure can. There are 2 end caps which complete the can. One end cap contains a thrust bearing and a ball bearing to completely support the shaft, as well as a dynamic shaft seal on the propeller shaft. The propeller shaft is attached to the motor shaft using a coupling with a rubber spider to take up any misalignment of the shafts thus preventing excessive vibration that could deform the seal. The rear end cap of the thruster is where the power enters the thruster, through a 2 pin Impulse bulkhead connector. A separate signal wire also enters the pressure can through a potted mini coax cable.

Figure 1 - Prop in Nozzle

Initially many different propellers having different diameters, pitches, and made out of different material were tested. After several unsuccessful attempts at generating thrust with metal propellers, the conclusion was reached that they were too heavy with too high of pitch. A number of plastic and composite props were then tested. It was found that with our motor, the small, light, low pitch props delivered the same amount of thrust at a much lower current than bigger, high pitch props. The propeller eventually chosen is 5cm in diameter, which is only 5mm larger than the housing for our thruster. This proved to be an advantage because it allowed us to easily mount a nozzle. This propeller will develop approximately 4 kg of thrust at 9 amp. The max continuous current the motors are rated for is 11 amp, therefore the chosen props allow the best performance out of the motors while maintaining a safe operational current.

The nozzle (Figure 1) we made is designed to help increase the overall thrust in a couple of different ways. The profile of the nozzle has features loosely based off a Rice Nozzle, which is similar to a Kort nozzle [4]. The throat of the nozzle is designed to be just slightly bigger than the propeller. This helps by directing thrust backwards. Without it, a lot of thrust would get lost off the tips of the propellers. From there, the nozzle's diameter increases with a 20^o angle. We designed this converging-diverging nozzle on the basis of conservation of mass, with respect to flow rate. Since the density of water is constant, with a reduction in area, the fluid must speed up according to:

$$\dot{m} = \rho \cdot v \cdot A \qquad \text{Eq. 1}$$

Where m is the mass of the system, rho is the density, v is the fluid velocity and A is the cross – sectional area.

So as the vehicle moves, the fluid is already moving faster as it hits the propeller than when it entered the nozzle. This will work in either direction since both sides are exactly the same (2).

Vision System:

The vision system of the PantheROV IV consists of four DLink DCS-900 Ethernet-enabled web cameras (3). which allows all video from the vehicle to be transferred to topside using a single Category-5 cable.

Contrary to using analog cameras and running separate coaxial cable lines for each camera, our vision design connects all of the cameras to a single Ethernet switch with patch Category-5 cabling and a single shielded Cat-5 cable is sent to the surface. Each camera communicates over the reliable Transmission Control Protocol (TCP) with a computer on the surface, sending Motion JPEG (M-JPEG) formatted files. The camera works by taking pictures at approximately 20 frames per second and sends them to the topside computer which uses software to reorganize the pictures into a motion picture.

At the front of the vehicle an acrylic viewing dome is built into the end cap of the main pressure hull. A pan/tilt capable DLink Ethernet camera is mounted to provide view through this dome. An issue with using a pan/tilt camera is the possibility of losing reference frame, or which way is forward. To fix this possible issue, the camera software contains center function which will return the camera to a direct center position.

The other three cameras are each encased in a 76.2mm diameter acrylic tube and mounted on the outside of the vehicle (Figure 2). One end of the tube, where the camera lens is located, is fashioned with a clear polycarbonate faceplate for a flat viewing surface.

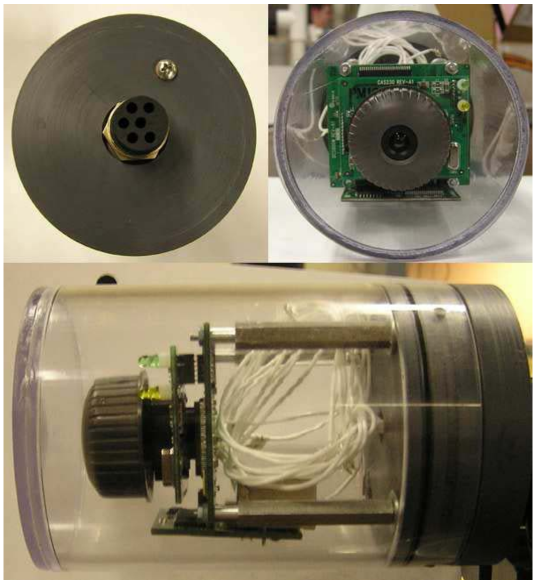

Figure 2 – Camera Housings

This end is sealed with clear acrylic cement. The other end of the camera tube is a removable end cap, constructed from Delrin, a plastic often used as a metal replacement. The end cap includes an o-ring seal, set screw groove, pressure release screw, and a 6-pin wet-pluggable Impulse connector. Each one of the cameras is mounted to the aluminum frame and connected to PantheROV IV with an Impulse-constructed cable.

Manipulator:

The manipulator for PantheROV IV is a rebuild of the one used on PantheROV III. The objective of this manipulator is to grab the 4.4kg "lava" samples during the mission. To achieve this goal the manipulator system is based off of a simple claw design which has flat area near the tip for grasping the soft and compliant fabric of the soft dive weights used as "lava".

The claw is constructed of 3.175mm aluminum plate held together with stainless steel fasteners. Aluminum was selected for the construction of the majority of the manipulation system due to its superior physical and mechanical properties. Its high strength to weight ratio allows for smaller pieces and ultimately less mass at the end of the arm, resulting in a more stable vehicle platform. Actuation of the claw is achieved through the use of a small DC gear motor. This motor turns a threaded shaft inside of a threaded block of aluminum to which the claw linkages are attached. As the shaft spins it pulls the threaded block forward or back which in turn opens or closes the claw. This system was selected for a number of reasons; first, the system cannot be back driven, meaning that unless the motor is turning the claw cannot be opened or closed manually. Second, the high gear reduction of the motor allows for relatively high torque at low speeds and low power requirements. This translates to the claw being able to grasp things firmly while maintaining a high degree of control and using a low amount of power. The claw has a maximum opening range of 12.7cm. The claw mounted in a fixed position on the frame of the vehicle for simplicity.

Electronics:

Power:

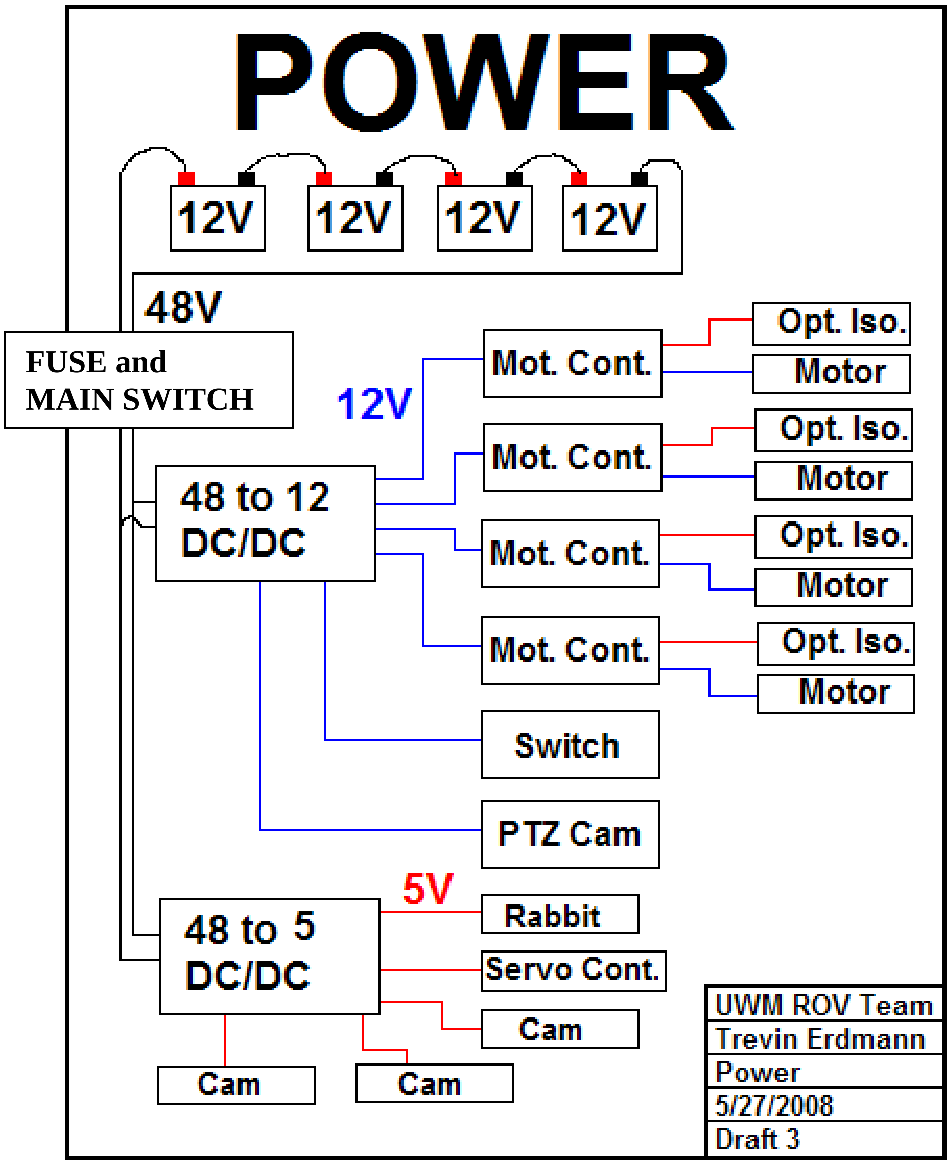

Figure 3 - ROV Power Distribution Schematic

To maximize power, with a limited 12 amp max, 48 volts will be run into the vehicle. To minimize the power loss due to resistance of the tether, it was re-engineered to reach all competition areas with minimal waste of line and power. Components on the vehicle, however, do not run off 48 volts. With the idea of maximum power, a heavy duty 48 volt to 12 volt DC/DC converter was obtained with the ability to provide nearly 1000 watts of power. This supply will be used to power motor controllers, motors, pan/tilt camera, and switch. For the electronics, a 48 volt to 5 volt DC/Dc converter was obtained with 100 watts of power. This supply powers the rabbit microprocessor, servo controller, cameras, as well as other various components on the electronics board (Figure 3). With this power format, a maximum of 9 amps could be drawn from the surface at full power, creating a safer, more reliable vehicle.

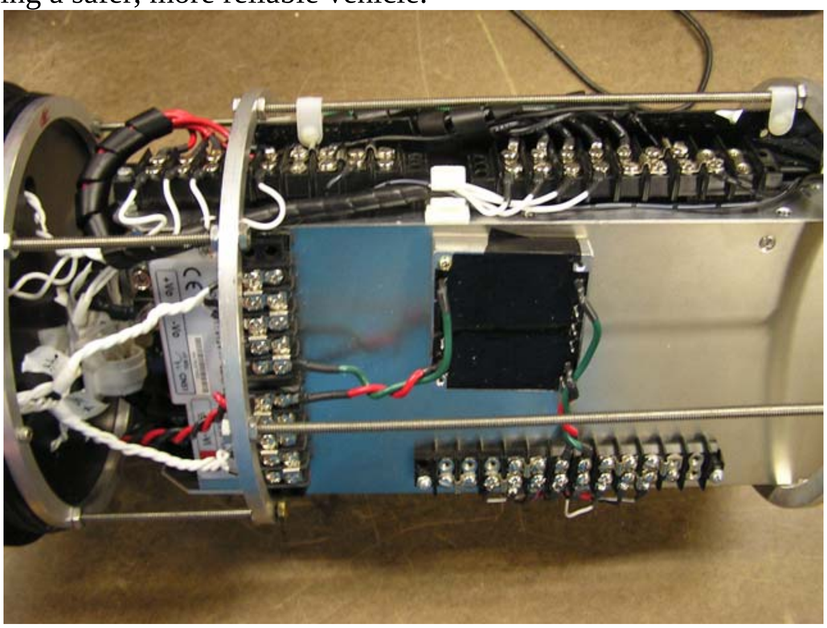

Figure 4 - Power Distribution System

Power was distributed throughout the vehicle using terminal strips (Figure 4). There are 6 strips on board the vehicle in total. One set is for the incoming 48v supply from the surface. This allows the 48v to be distributed to the 48v to 12v DC/DC and the 48v to 5v DC/DC. The 48v to 12v DC/DC converter is then connected to a heavy duty terminal strip, to distribute the 12v load. The 48v to 5v DC/DC likewise is connected to a set of terminal strips. It was necessary to use a power and ground terminal strips due to the use of isolated power systems, as discussed in the next section.

At the surface, the tether terminates through the power control box. This box contains the necessary 40 amp fuse, as well as a power disconnector and the main power switch. The power disconnect is an addition to the PantheROV IV vehicle system. The power disconnect is basically a key that will physically disconnect all power to the system, before the main switch. This was installed as an additional safety device, which working on dangerous components such as the propellers or the high current 12v outputs, the key can be removed to ensure a switch can't be bump inadvertently. The tether then ends in a battery ring terminal to access the supplied power for the competition.

Electronic Isolation:

In order to provide a reliable vehicle, isolation of electronic components from possible power surges is a must. This was the first year brushless motors were used for the thrusters. To alleviate possible damage to electronics due to voltage spikes off components, such as the brushless motors, opto-isolators (OIs) were designed and used to isolate the sensitive control components (the servo controller and the Rabbit microcontroller) from the possible noise generated by the brushless motors.(Figure 5) The isolator transfers electronic signals to the motor controller through an LED and sensor, eliminating the electrical continuity between the thruster and the main electronics board. An inverter had to be installed to invert the signal before the opto-isolators due to the inversion occurring in the opto-isolating process.

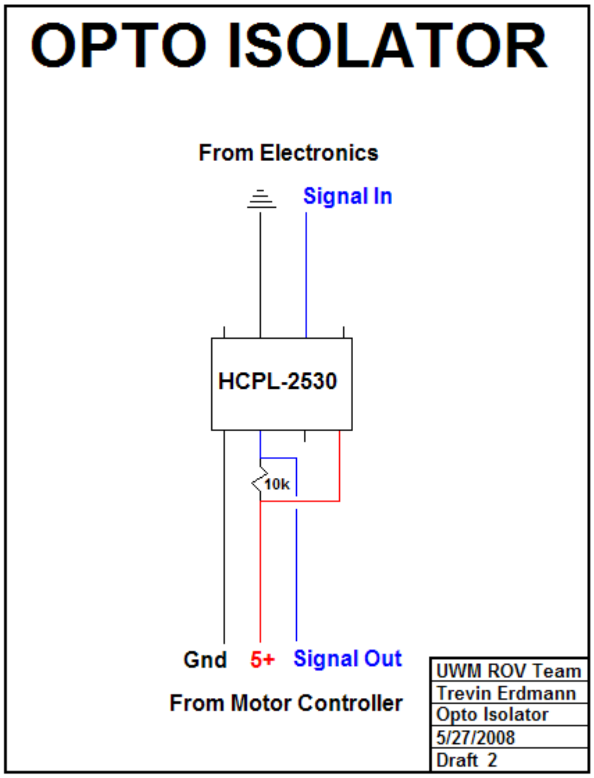

Figure 5 - Optoisolator Circuit Schematic

To limit the number of connections to be run into the thruster housings, the optoisolators were designed to be put into the housings, and conveniently the OIs are powered by the motor controllers. The Dynamite RC brushless motor controllers are built to supply a 5v signal to control devices, so it was only necessary to run a ground and a signal (in terms of low power signal wires) into the thrusters, through the OIs.

Software:

PantheROV IV is controlled using multiple small interconnected electronic systems (Figure 6). Within the ROV a small microcontroller handles many tasks including: input and output over TCP/IP, reading and converting temperature readings, and communication over a serial port to the servo controller. The servo controller is a small device that receives a string of commands from the microcontroller and generates signals that are sent to servos. In our case our brushless motors all have their own ESCs (electronic speed controller) which interprets the PWM signal and controls the motor's duty cycle. This enables us to have the microcontroller to act as sort of the brain of our ROV and save time by not focus so much on low level PWM generation.

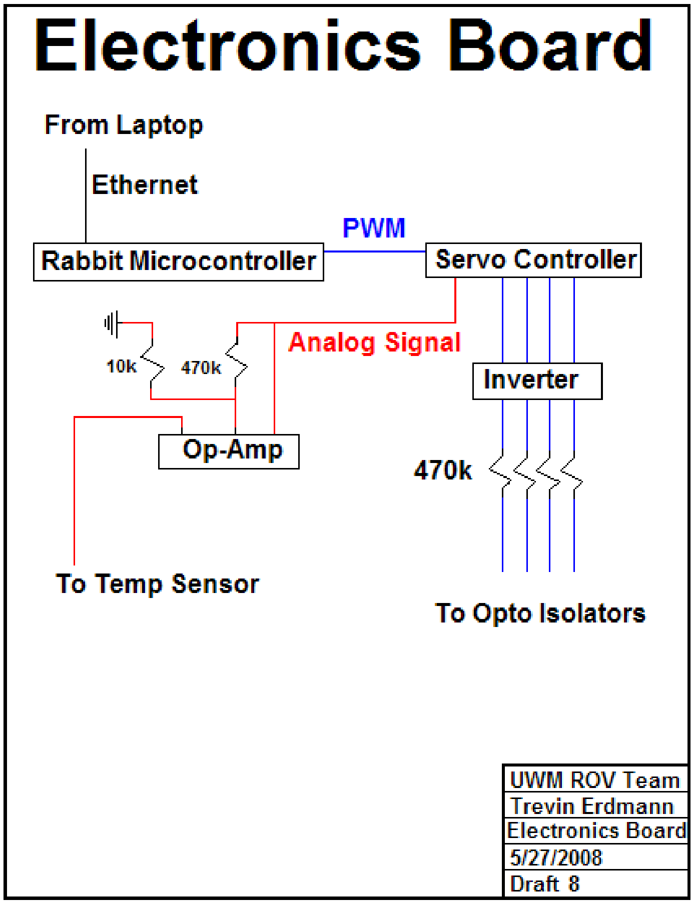

Figure 6 - Electronics Board Schematic

For the servo controller we used a Lynxmotion SSC-32 . This servo controller works by receiving an ASCII string of commands from the microcontroller and emitting the correct PWM signal on the selected channel. Servos require a pulse every 20ms and measure the width of the signal. This width corresponds to the servo position.

Example:

Say we wanted to set servo one to 0 degrees. The microcontroller would send the command "#0 P1500\r". This would be processed by the servo controller which would send a pulse width of 1.5ms to the servo. (An example of this wave form to the right, Figure 7)

The SSC-32 also offers many advantages such as concurrent servo movement and allowing control of up to 32 servo type devices. In addition it offers a 4 channel on board 8-bit analog to digital converter. These included features enabled us to spend more on other essential systems.

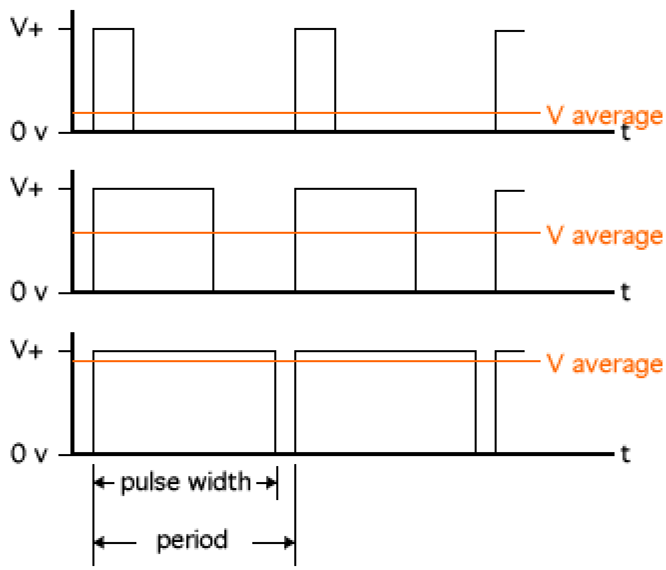

Figure 7 - PWM Waveform Example

ROV Microcontroller:

The commands transmitted by the topside computer are processed and executed by the Rabbit RCM 3700 microcontroller. It was chosen because of its flexible design, which includes 31 digital input/output lines and an Ethernet controller. Some of the digital I/O lines can also be configured to be used as Pulse Width Modulation (PWM) ports and serial ports, although this was not necessary for the PantheROV IV. To program the microcontroller, a programming language called Dynamic C is developed on a PC. The language itself is much like the standard C programming language, with the addition of libraries and keywords that are specific to the Rabbit hardware. In order to transfer a program to the RCM 3700, it is *cross compiled* over a serial programming cable. The act of *cross-compiling* converts the machine code from the architecture of a PC to one that the microcontroller processor can understand (4).

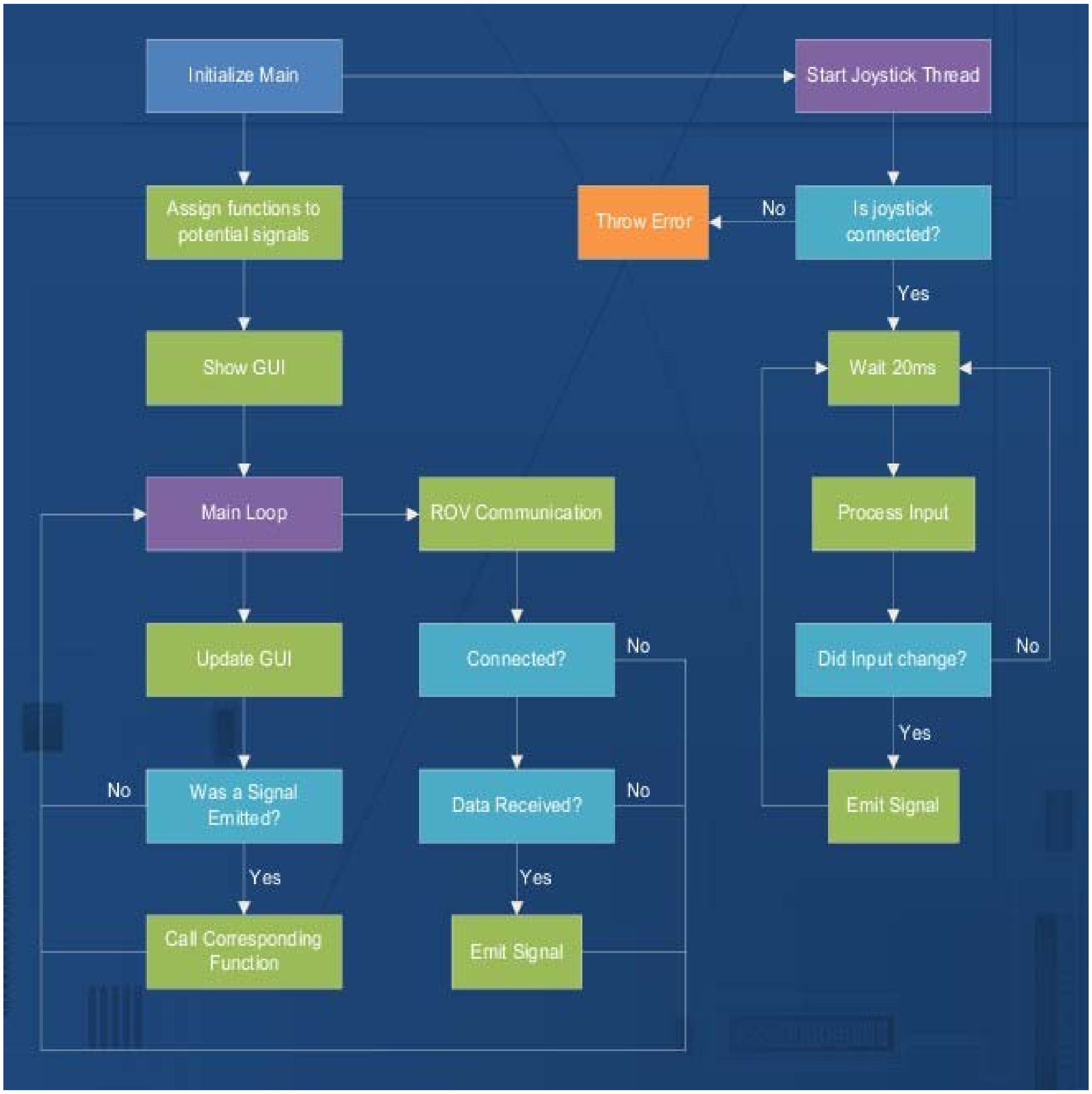

Figure 8 - Software Flow Chart

Topside:

The top side software is what we use to control the ROV. This year the software was written in the Python programming language which offers many productivity benefits and cross platform support, meaning it can be run many operating systems without requiring modification to the program. Python is an interpreted language which means that when the source code is run through the python interpreter it is translated into more efficient intermediate code which is immediately executed. By using an interpreted language when changes are made to the source code all one must due to see the effects in the program is restart it (Figure 8).

The internal design is split up into 3 modules; User Interface (GUI), Communication, and Joystick Control. It is all brought together in the Main program. This helps manage code and functionality. Also by developing the modules individually I was able to include a test driver for each to help trouble shoot different parts of the module and ensure proper functionality.

The GUI was built using PyQt4, which is a Python binding for the powerful Qt4 library. Qt's GUI library is used by many large software companies in popular applications such as Google Earth and the Linux version of Mathematica. This was built using Qt Designer which provides a visual way to create the front end you will see. It then automates the tedious task of creating the necessary code to place the proper visual objects in the right place. This allows the visual objects to then be connected to functions. Such as when a button is clicked it will emit the signal “clicked()”. This signal can be connected to a function that will execute when ever the signal is sent.

Communication uses TCP/IP over Ethernet to for sending and receiving data between the micro controller and top side software. The module contains all the functions for connecting to the ROV and sending it movement commands. When a movement function is called it creates the proper array of values and sends them to the micro controller.

The Joystick module emits signals related to the input, these signals are then detected in the main program which connects them to a function. For joystick signal interpretation a python wrapper for Simple DirectMedia Layer (SDL) was used. SDL's Joystick API provides an easier way to read values from USB gamepads. This module contains two classes, ROVJoystick, and ROVJoystickThread. The ROVJoystick contains the function run to process new input and emit signals which must be called regularly to read joystick actions. The ROVJoystickThread creates it's own thread and ROVJoystick object which is then told to process input every 50ms. By running ROVJoystick in its own thread, it can execute its operations independent from the main program.

Hydrothermal Vent and Mid Ocean Ridge Exploration

Figure 4 - R/V Atlantis

Currently the former president of the ROV Team at UWM, Mr. Korey Verhein, is employed by the Woods Hole Oceanographic Institute (WHOI) as a ROV technician on the R/V Atlantis. As an ROV technician for Jason, Korey is a member of the team which double checks and prepares Jason for launch. He is also being trained as a pilot for the submersible Alvin (21).

The R/V Atlantis and the Alvin/Jason team are currently studying hydrothermal vents and underwater volcanic ranges in the Pacific Ocean. This research vessel is the only one of its class set up to both launch the submersible Alvin, as well as perform oceanographic research. There are five separate labs on the research vessel, to perform direct analysis with the ocean, as well as analyze samples retrieved by the submersibles (22).

The research being performed by this vessel and ROV can be directly compared to the type of tasks that are assigned for the competition. The difficulty and complexity of designing and launching a reliable submersible system can be seen by all of the teams participating in this years competition.

Troubleshooting Techniques

A major troubleshooting technique used on PantheROV IV was working backwards to isolate the point of "trouble". During the initial dry power-up of the vehicle No signal was reaching the thrusters. To find out where in the signal chain the problem was, we started at the motor controller in the thruster and worked backwards testing the continuity of all connections and then using an oscilloscope to test the waveform at that particular junction. By using this method we found that the signals were being lost at the output of an inverter chip. The data sheet for this inverter was consulted and it was found that the inverter had been wired incorrectly on our control board. We re-soldered the connections properly and the next dry test of the vehicle was successful.

Lessons Learned

As has been the case for the past three years, time management was a difficulty for the team this year. As the qualification deadline approached, it was realized how much work was left on the vehicle. The team began working every evening for several hours, on top of numerous hours during the day to complete the vehicle for qualification. The majority of the team was first year participants in the competition, and they soon found out why the previous teams clamored about time management so often. Now that a reliable platform has been established, with properly managed time next year, a stellar vehicle can be completed.

Reflections

Through my first year experience working on the ROV, I have learned many things. The most significant lesson learned was to not worry about doing anything wrong, but to start working and learn as I go. Being a new member, as well as early in my engineering studies, I did not have the initial knowledge of what needed to be done. This created a hesitancy to work on my portions of the vehicle. As I learned, though, when I started working I was able to learn as I go and get my portions of the vehicle designed, tested, and finalized efficiently. I just needed to understand that, though some of my projects may not work the first time, I was able to learn why and fix my projects to working status.

--- Trevin Erdmann

This is the 4th year that I have been participating in the MATE International ROV competition. The past 3 years I have worked on various mechanical systems of the past three iterations of the PantheROV vehicle. This year I was given the keys and was the president of the team. This was a much more challenging role than I ever would have thought. Managing the team to ensure that all aspects of the vehicle were being covered, while making sure the necessary paperwork was being completed on time was difficult, but even with an all rookie team, we were able to complete the vehicle. I learned that in order to manage a project such as this one, you have to be sure to stay on top of everything, because things don't just happen, you are the one that makes sure they happen, and then the great team you are working with follows through to finish what is needed.

-- Greg Oswald

Challenges

A major challenge faced by the team this year was the continuing difficulty in obtaining and spending money for the vehicle. The majority of the vehicle is funded by grants from the UWM Senate Appropriations Committee (SAC) and then the money is distributed by the Student Activities Office (SAO). Because of mishandling of funding by other organizations, the paperwork for expenditures has increased significantly. Also the policy has changed so reimbursements are not recommended, therefore all purchases have to be approved through SAO. This means that all orders take around 3 weeks to be processed and completed. To overcome these challenges, the team had to plan early as to what purchases had to be made, and get the paperwork in early, to allow for the ordering to take place.

These delays were not a major issue in the fall semester of 2007, however after January 2008, the ROV Team was required to be evaluated by University Risk Management, before any purchases using University money could be completed. It took approximately 4 weeks to complete this evaluation. This effectively set the progress of the team back by one month. After the evaluation was completed, the orders were completed meaning that it was 6 weeks before the first parts order of the spring semester was received. This resulted in a loss of momentum and the team had to overcome this challenge by putting in long hours in the last month before the qualification to complete the running vehicle.

Future Improvements

PantheROV IV has proven to be a very reliable system during testing, however there are a few areas that could be further developed. One major point in the vehicle construction that needs to be addressed is the signal wire running into the thrusters. The power and signal wires enter the thruster housing at two different points, the power through a large 2 pin Impulse bulk head connection. Unfortunately there was not enough time to purchase a larger bulk head connector that could support both power and signal. Therefore the signal enters the thruster through a potted mini coaxial cable. The pot is reliable, however because all 4 thruster signal leave the main pressure hull from a single 8 pin bulkhead connector, all 4 thrusters are permanently connected together. Installing a 4 pin or larger bulk head connector for each thruster would aid in assembly/disassembly of the vehicle.

Another aspect of PantheROV IV that can be improved upon is the construction of the electronics boards. For quick development all boards were hand wired and soldered. This unfortunately leaves the possibility that one of the 30 gauge connector wire could be damaged. A printed circuit board would prevent this and would be a great future improvement to the vehicle.

An additional improvement that would be helpful in the piloting and stability of the vehicle would be a multipoint active buoyancy system. A system like this could allow the vehicle to self level itself, or tilt to a pre-decided angle. This system could also aid in the recovery of larger payloads, by increasing the positive buoyancy of the system, the amount of thruster power needed would be reduced.

2008 Budget Sheet

Purchased Items				
Description	**Vendor**	**Quantity**	**Unit Price**	**Total**
Brushless Motors	Astroflight.com	5	$89.95	$449.75
Motor Controllers	Dynamite RC	5	$59.99	$299.95
SSC-32 Servo Controller	Lynx Motion	1	$39.95	$39.95
Shaft Couplers	McMaster Carr	5	$5.83	$29.15
48v - 12v DC-DC converter	TRC Electronics	1	$349.99	$349.99
48v - 5v DC-DC converter	TRC Electronics	1	$89.00	$89.00
Purchased Grand Total:				$1,257.79
Reused Vehicle Components				
Description	**Vendor**	**Quantity**	**Unit Price**	**Total**
Closed-Cell Foam	US Composites	1	$54.00	$54.00
Robotic Arm Materials	Various	1	$55.00	$55.00
Spare Microcontrollers	Rabbit Semiconductor	2	$59.00	$118.00
Glues/Epoxies	Various	1	$50.00	$50.00
Aluminum Frame Tubing	SpeedyMetals	1	$50.00	$50.00
General Electronic Components	Jameco	1	$135.00	$135.00
Frame Interconnects	Holliander	1	$200.48	$200.48
Waterproof Connectors	Impulse	1	$817.00	$817.00
Dlink DCS 900 Webcams	Buy.com	4	$82.99	$331.96
Linksys Ethernet Switch	Buy.com	1	$42.99	$42.99
203.2 mm Aluminum Hull	SpeedyMetals	1	$63.06	$63.06
RCM 3700 Microcontroller	Rabbit Semiconductor	1	$59.00	$59.00
Reused Grand Total:				$1,976.49
Travel Expenses				
Description	**Vendor**	**Quantity**	**Unit Price**	**Total**
Flight	AirTran	5	302.5	$1,512.50
Housing	University of Cal. - San Diego	5	205	$1,025.00

Donated Parts/Services		
Description	**Vendor**	**Quantity**
38 m Shielded Twisted Pair	Igus	1
38 m 4 Conductor 10 AWG cable	Igus	1
Pressure Hull Machining	Hammel Tool and Die	1
Shipping of Vehicle	WATER Institute	1

Acknowledgements

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

University of Wisconsin-Milwaukee:
College of Engineering and Applied Science at UW-Milwaukee
Mike Brown - UWM Machine Shop
Senate Appropriations Committee (SAC)
Student Activites Office
Tom McGinnity - Assistant Dean of Students
Jennifer Lyon - Business Manager

Companies:
Hammel Machine Products
Bearings, Inc.
Impulse Enterprise, Inc.
IGUS, Inc.
Metallurgical Associates, INC
Edmund Optics, Inc.
Speed Rail
Generic Logic

References

(1) Astroflight Inc.
3311 Beach Ave.
Marina Del Rey, CA 90292
(310) 821-6242
http://www.astroflight.com

(2) http://www.olds.com.au/marine/maximizing_propulsion_efficiency/index.php

(3) D-Link Corporation
No. 289, Sinhu 3rd Rd,
Neihu District,
Taipei City 114,
Taiwan, R.O.C.
886-2-6600-0123
http://www.dlink.com/

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

(21) Korey Verhein, Woods Hole Oceanographic Institute

(22) http://www.whoi.edu/page.do?pid=8143
PantheROV III Technical Report

Figure 2 - http://www.micromouseinfo.com/introduction/images/intro_hardware/PWM.gif

Figure 3 - http://www.whoi.edu/page.do?pid=8143