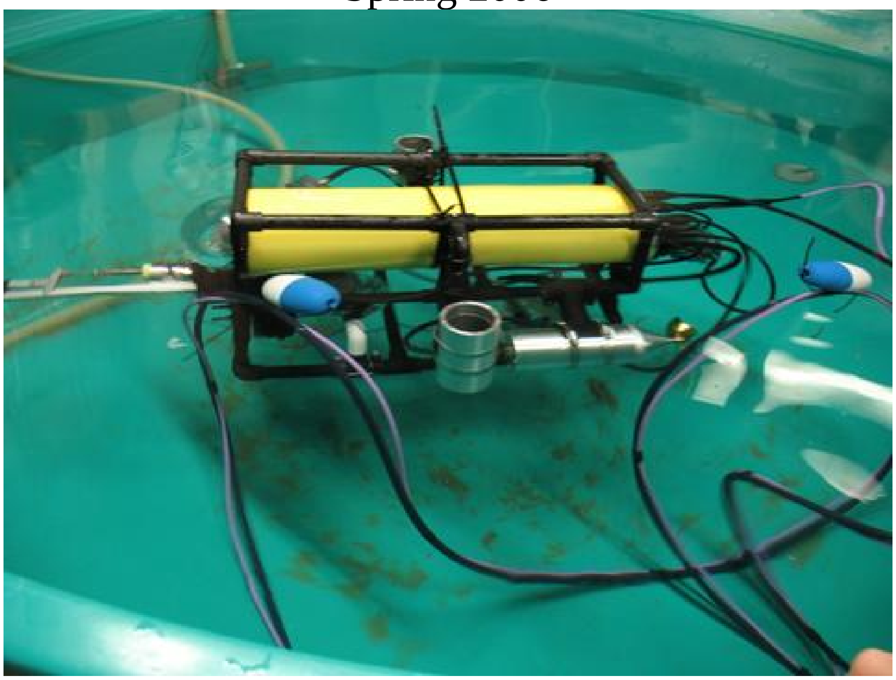
ROV Team

at
University of Wisconsin-Milwaukee
Explorer Class

MATE National ROV Competition
Spring 2006



"PantheROV II"

Mentor: Dr. Tom Consi

Team Members	Major	Standing
Dave Bogdan	Materials Engineer	Senior
Chris Brenny	Mechanical Engineer	Senior
Joe Brenny	Mechanical Engineer	Senior
Rob Brummond	Mechanical Engineer	Senior
Chris Chudy	Mechanical Engineer	Junior
Dan Kiedrowski	Materials Engineer	Senior
Mark Marcott	Computer Science	Senior
Don Murray	Electrical Engineering and CS	Senior
Greg Oswald	Materials Engineer	Senior
Andy Schneider	Computer Science and EE	Junior
Korey Verhein	Computer Science and EE	Senior
Josh Zagorski	EE and Physics	Senior

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Abstract

We engineered and built an underwater Remotely Operated Vehicle (ROV) with the capability of completing the construction of an Ocean Observing System (OOS). The ROV will have to deliver an electronics module to a trawl resistant frame. Also, two cables need to be connected to the electronics module for power and communication for a submarine and a scientific instrumentation station. One cable is located nearby and the other needs to be laid along a route before being connected. To simulate the ocean environment we will be testing our vehicle at NASA's 13 meter deep Neutral Buoyancy Lab at Houston, TX.

Our vehicle's main dry hull is a sealed aluminum tube with an acrylic dome for the main camera view (Figure 1). The vehicle has four aluminum housed thrusters mounted on a PVC frame to allow for movement in the horizontal and vertical axes. A Rabbit microcontroller (1) is the main on-board vehicle control system which is fed commands by a Visual Basic program running on a laptop located topside. Three ethernet video cameras mounted in acrylic tubes serve as the external auxiliary vision system, while the main camera is mounted on a tilt and pan system inside the dome of the dry hull. Mounted at the base of the frame is a payload release system composed of a solenoid positioned to hold the electronics module in place during delivery. Lastly, there is a manipulator with its gripper actuated by a dc gear motor.

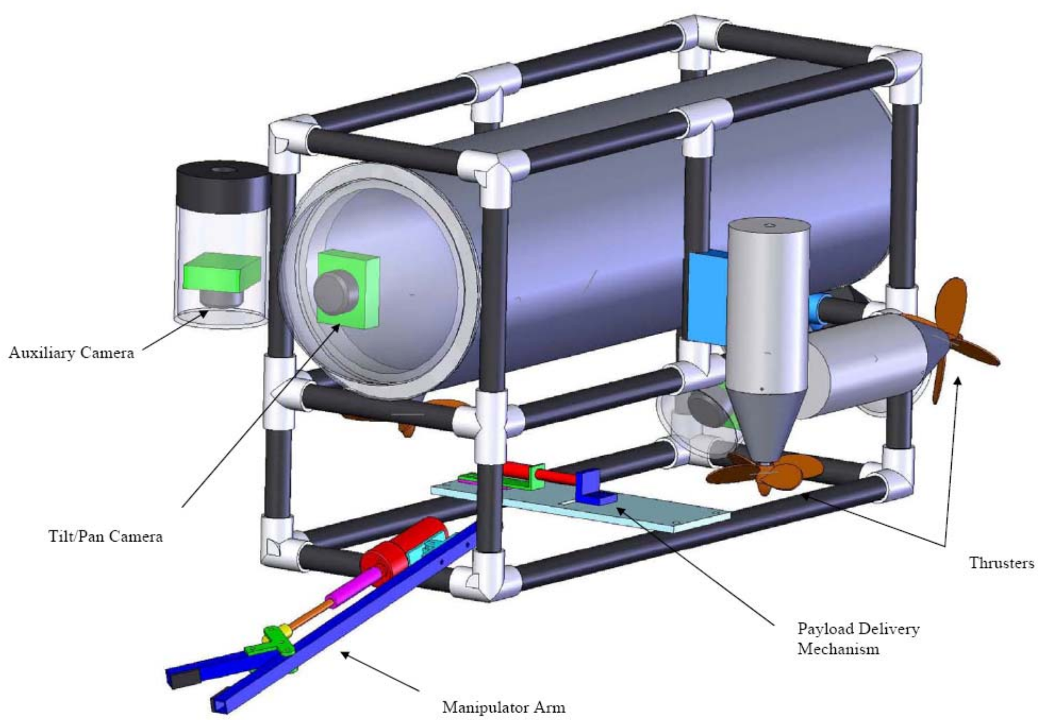

Figure 1: Vehicle Layout

Design Rationale

The most important aspect of this mission is the delivery and mounting of the electronics module. The vehicle was designed mostly around the positioning, mounting, and delivery of this package. Our vehicle last year, the PantheROV I, was very underpowered and had a great deal of drag. The second consideration, therefore, was to include higher power thrusters and to make them robust enough to be reusable for any future competitions along with a more hydrodynamic frame.

Thruster:

The major goal in the design of the thrusters was to create a pressure proof housing for the most powerful electric motors that were within the power budget. The major design challenge was to develop a dynamic seal that can withstand sustained pressures of 60 psi. We were able to find a seal with help of a local merchant, which is manufactured by Chicago Rawhide (Figure 2) (2). It is rated to 90 psi at the speeds our motors run at. The major problem with the seal is that its effective sealing diameter is 7.9375mm. However the bearings and the shaft couplers were designed to be 6.35mm, this led to some problems with the initial design.

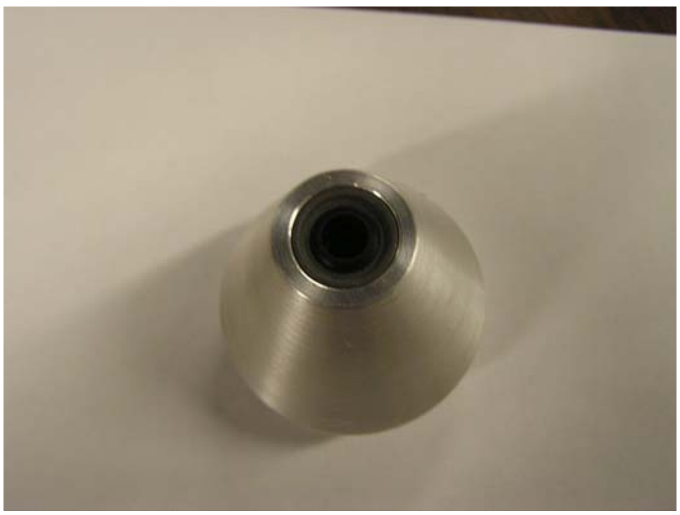

Figure 2: Shaft Seal

The original design was developed to be assembled in a certain order. With the larger diameter needed for the seal, this order was disrupted. The mistake was not caught until after machining of the prototype housing was begun. A few design changes were made to allow the final assembly of the housing to take place, but the change compromised the integrity of the housing. The housing was not water proof but after careful inspection it was determined that it was not the seal that breached, but an access hole that had to be added. The current design eliminates the need for an access hole and reduces the number of places for a breach to occur to 3 areas, the dynamic seal, the static o-ring seal, and the bulk head connector.

Figure 3: Thruster Motors

Astroflight Cobalt 40 (3) motors (Figure3) were chosen largely because of a generous donation from Rob Paddock, a researcher at the UWM WATER institute, of 3 of these motors. They are high current motors capable of running 12-24V. The motors will be run at 24V drawing approximately 7 amps. The 24V ability is useful because more power can be generated by the motors while using roughly the same current, helping reduce strain on the power budget.

Several considerations went into the choice of propellers to be used. They needed to be strong enough to handle high rotational speeds underwater as well as creating high amounts of thrust while resisting cavitations. The props that were chosen are manufactured by Harbor Models (Figure 4). They are 100mm in diameter and made of brass. When the propellers were purchased they were bought in opposite pairs. By rotating a right handed and left handed props in opposite directions, thrust can be achieved while eliminating torque from the spinning propellers. This will create a more stable platform overall.

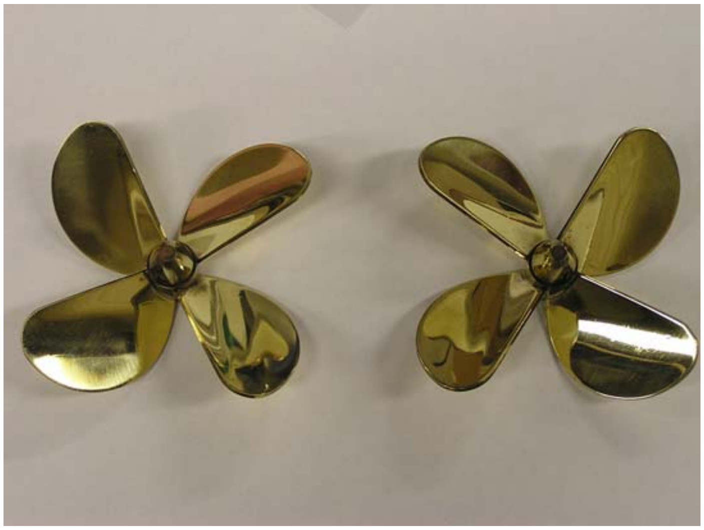

Figure 4: Propellers

The final thruster component is a bulk head connector manufactured by Impulse Enterprises (4). The Impulse connectors are wet-pluggable which means that even if both ends of the connectors are wet they can be connected without risking a short in the system. The connectors are rated to a pressure of 20 000 psi.

Thruster Housing Design:

The top assembly consists of the motor, with a shaft extension coupled on by a two part pliant coupler (Figure 5), attached to the cone by the motor mount. The pliant coupler is important because as the motor is spinning any eccentricities of the shaft can lead to breaches in the shaft seal.

Figure 5: Pliant Coupler

The cone is a very important part of the thruster design (Figure 6). The shape was chosen to increase water flow around the housing. However the main job of the cone is to hold 2 sets of bearings for the shaft and the dynamic seal. This is where all moving parts pass through, sealing in this area is critical.

Figure 6: Thruster Cone

The top assembly then is attached to leads from the bulk head connector and inserted into the cylinder. The cylinder is threaded at the bottom to hold the bulkhead connector and has 3 set screws at the top to hold the top assembly in place. There were also slots cut into the top edge of the cylinder to aid in the removal of the top assembly, a flat screw driver can be used to pry the cone upwards. This feature was needed because of the tight seal the static o-ring creates.

For the actual construction of the cone, cylinder and motor mount 2 materials were considered, plastic and aluminum. Initially a Plexiglas cylinder with a Delrin cone was considered. This would have been useful because the inside of the housing can be inspected without dismantling the entire thing. However the motors that are being used tend to generate fairly high temperatures, so it avoid overheating problems, it was decided to use aluminum in the construction. Aluminum was ideal because of the high thermal conductivity light weight and its resistance to oxidation.

The cylinder of the thruster housing was designed to have a bottom plate on it to eliminate the need for an end cap. This removes a seal and reduces the change for a breach which creates a more reliable pressure housing (Figures 7 and 8).

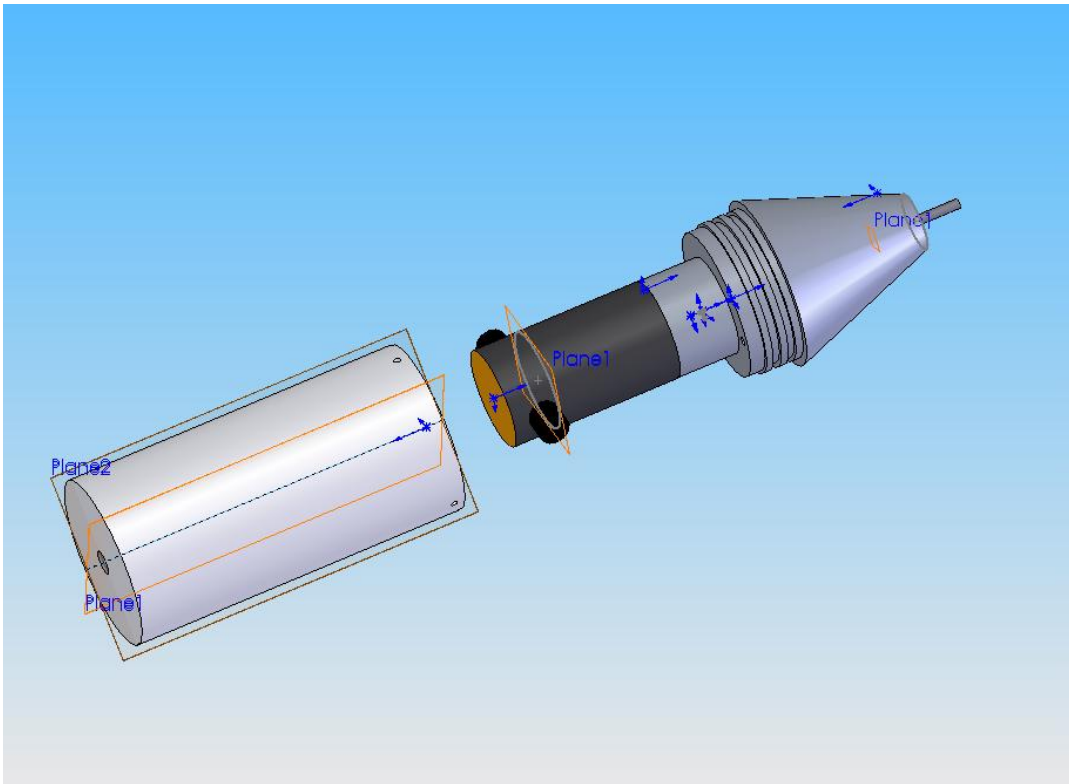

Figure 7: Thruster Exploded View

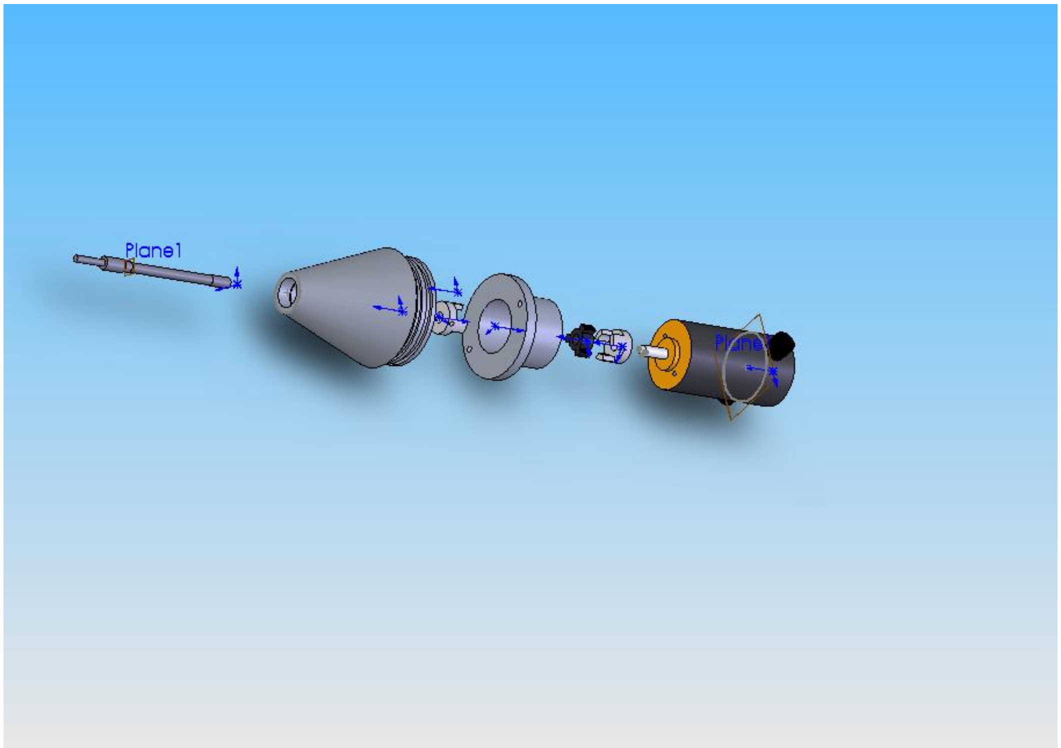

Figure 8: Shaft Assembly Exploded View

Payload Delivery System:

The objective of the payload detachment system is to release the electronics module after it is placed in the trawl-resistant frame. The electronics module has five U-bolts set into it for lifting. Four of these are set in each corner and the fifth is set in the center of gravity for the module. To reduce the complexity of the payload detachment system only the center U-bolt is used for lifting and detaching.

The actuator chosen for this system is a solenoid, in order to mount the electronics module without the need to power up the whole vehicle and to simplify the controls necessary to dispatch the payload (Figure 9). Solenoids are readily modified to be watertight and are very simple to actuate. When a 12 V potential is applied to the solenoid it retracts a solenoid pin. In the system a solenoid pin mated to a receiver plate carries the payload. The retraction of the solenoid pin allows for the detachment of the payload.

The receiver plate has a counter-bored hole with a diameter matching the solenoid pin so that the load is carried on each side of the pin. The solenoid and receiver plate are mounted on a piece of 6.35 mm clear polycarbonate plastic mounting plate to allow for an unobstructed view of the payload in transit. The mounting plate has a slot to allow the 50.8 mm U-bolt to pass through it. The mounting plate is attached directly to the ROV frame. A solenoid bracket secures the solenoid and a spacer placed between the mounting plate and the solenoid bracket positions the solenoid pin to allow it to mate with the receiver plate. Both the receiver plate and the solenoid bracket have slotted holes to allow for over 25.4mm of adjustment.

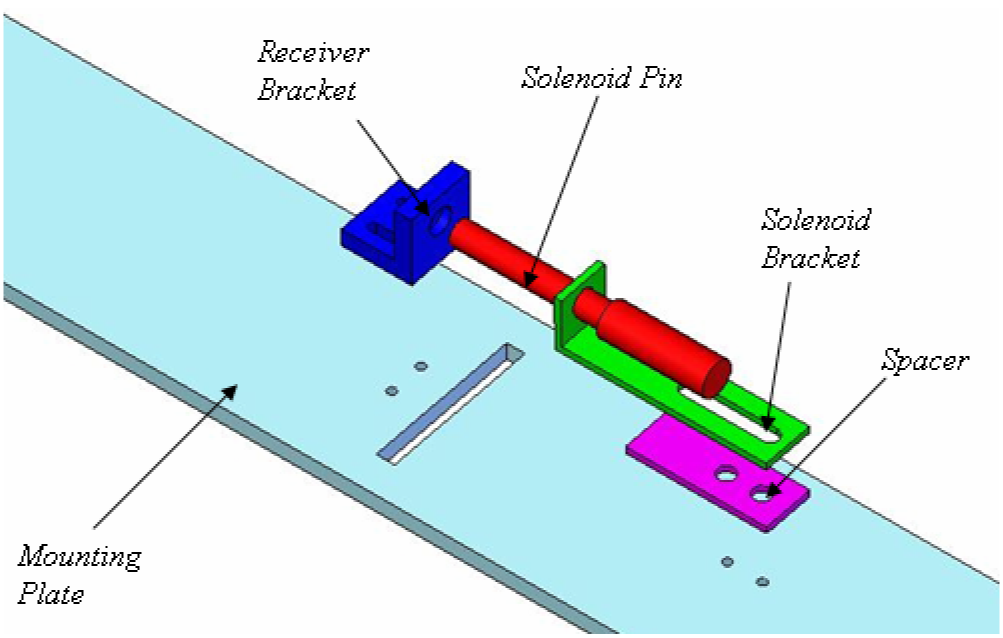

Figure 9: Electronics Module Delivery System

Manipulator Arm System:

The objective of the manipulator arm system is to hold and release mission critical objects. The manipulator arm system must open the door of the trawl resistant frame to access the open ports of the electronics module, connect cable connectors into the open ports of the electronics module, pick up and lay instrument cable through assigned waypoints. To reduce the complexity of the manipulator arm system the arm is fixed to the ROV and only one jaw of the manipulator arm is actuated (Figure 10). The manipulator arm can only hold and release objects, all other manipulation of the objects is accomplished by the ROV thruster motors. The actuator chosen for this system is a DC gear motor. DC gear motors are readily modified to be watertight and are very simple to actuate. DC gear motors apply a large amount of torque with a small draw of current. In our system a DC gear motor rotates an internally threaded collar mated with a threaded rod to provide rotational to linear motion. The threaded rod is connected to a clevis which is pinned to the jaw hinges. The jaw hinges are fastened to the upper jaw and pinned to the lower jaw mounting brace. The upper jaw and lower jaw mounting brace are constructed of 12.7mm aluminum tubing. Both the upper jaw and lower jaw mounting brace are equipped with rubber jaw grips to provide holding friction. The DC gear motor is connected to the lower jaw mounting brace by a tilt motor base that allows for the upper jaw's range of motion. The manipulator arm system allows for 76.2mm of jaw actuation.

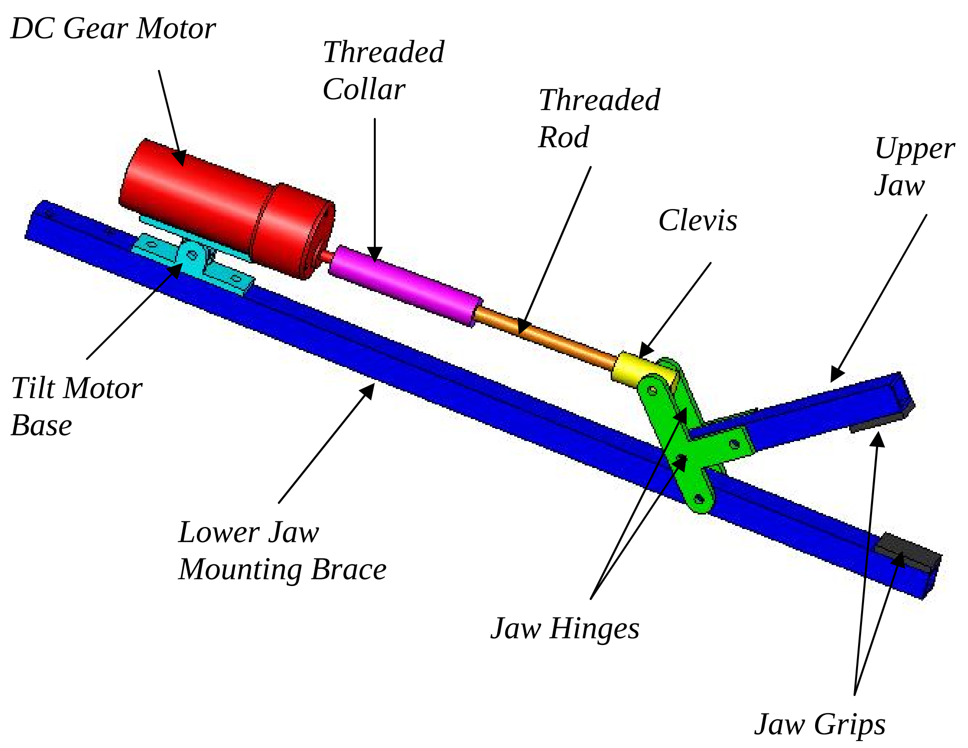

Figure 10: Manipulator

Hull and Frame:

PantheROV I failed when faulty cabling and a faulty pass-through system allowed the electronics dry hull to be flooded. To solve that problem, this vehicle's design utilizes Impulse bulkhead connectors for all external systems. Easy access to the hull was a key part of the design. The easiest way we thought we could achieve this while keeping it waterproof was to have a cylindrical hull with a cap on one end with o-rings and set screws to latch the cap to the hull. An 203.2mm OD, 6.35mm wall thickness aluminum pipe was used as the hull. Aluminum was chosen for strength, machining ability, light weight, and for the dissipation of any heat given off by the electronics, especially the DC-DC converters and motor controller circuits. The large diameter pipe was chosen to provide ample space for all of the electronics circuits and to provide moving room for the main camera, housed behind an acrylic dome on the front side of the hull. A PVC frame lines the sides of the hull which provides mounting points for the thrusters, auxiliary cameras, manipulator, and payload delivery system.

Tether:

The tether is comprised of two cables: one Ethernet cable and one composed of 4 #10 AWG stranded wires for power. The Ethernet and power cables were chosen for their relative flexibilities and lighter masses. To avoid signal interference from the power cable or any random signals the Ethernet cable was further specified to be shielded. The Ethernet cables uses will be described along with electronics/software. Neither cable is "waterproof," but they are sufficiently water resistant to avoid interfering signals or shorts. The problem of the cables leaking last year is not remedied by waterproof cables, but by the Impulse bulkhead connectors' isolation of the cable from the inside of the hull. The gauge of the wires in the power cable was selected to ensure the least possible voltage drop across the length of the cable while being able to handle a current of up to 40 A. One #10 AWG wire is not rated to handle 40 A, but two of these wires in parallel will be able to handle up to 60 A.

Electronics:

The goal of the electronics design was to provide necessary functionality using as simple a circuit as possible, while maintaining enough flexibility to make changes if our testing deemed them necessary. The circuit design is very similar to last year's vehicle, with modifications aimed at providing greater reliability and performance.

Power:

The ROV is powered by a 48V supply consisting of four 12V car batteries connected in series. Power is supplied to the vehicle by a tether from topside, and the power line is protected by a 40 amp fuse to ensure safe operation and compliance with mission specifications. The tether connects to the watertight hull through Impulse bulkhead connectors. On board the vehicle, the thruster motors are connected directly to the 48V bus. A 48V to 12V DC to DC converter steps down the voltage for use by the thruster motor relays, solenoids, ethernet switch, and cameras. A number of voltage regulators step the voltage down to 5V or 3.6V for use by the remainder of the on board electronics. The low power electronics are situated on a printed circuit board that was designed using ExpressPCB software (5) . The relays, high power transistors, and terminals of high power devices (i.e. thruster motors and solenoids) are mounted onto a separate prototyping circuit board.

Control:

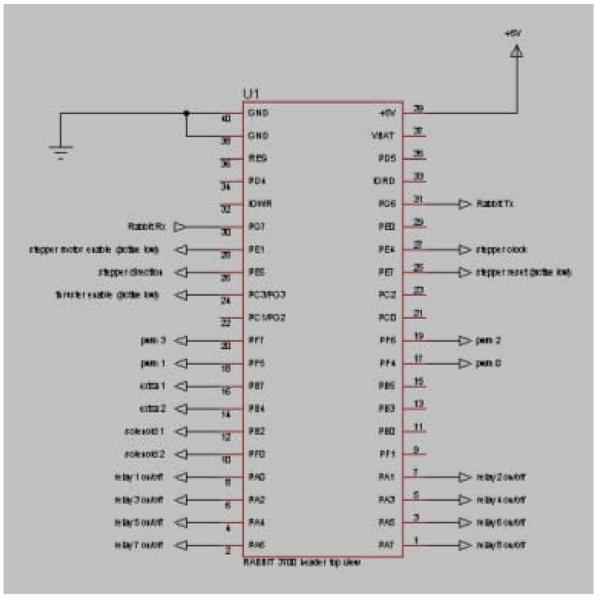

Figure 11: Rabbit Pinout

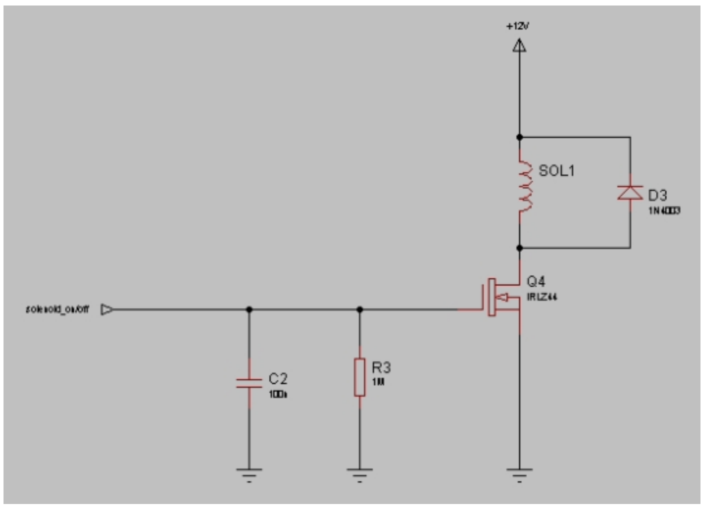

Figure 12: Solenoid Circuit

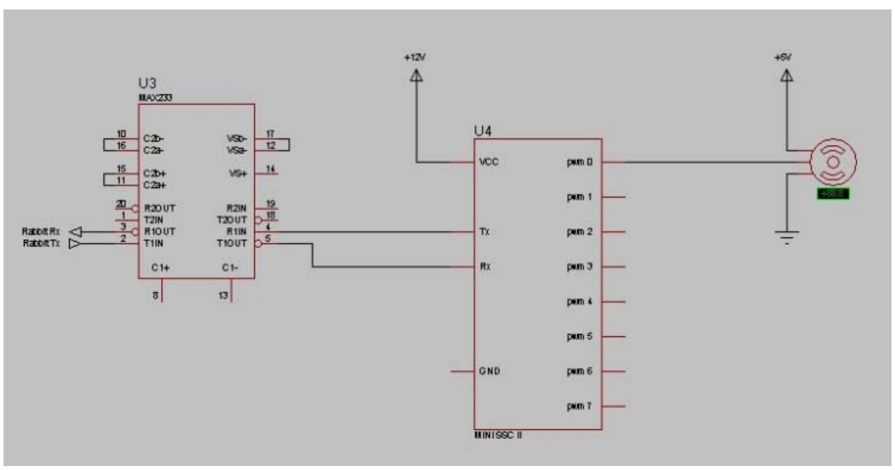

Figure 13: Servo Controller

Control of the vehicle is provided by a Rabbit Semiconductor microcontroller (Figure 11). This device was chosen due to its large amount of digital input and output, ethernet communication port, and hardware implemented pulse width modulation. The Rabbit receives commands from the topside controller, and selects the appropriate operation of the thrusters, servos, and solenoids. For driving solenoids (Figure 12), digital input and output pins are connected to the gates of power MOSFETS, which act as on/off switches for the high current solenoid circuits. Servos are operated using pulse width modulation generated by a Mini SSC II servo controller (Figure 13).

Thruster Motors:

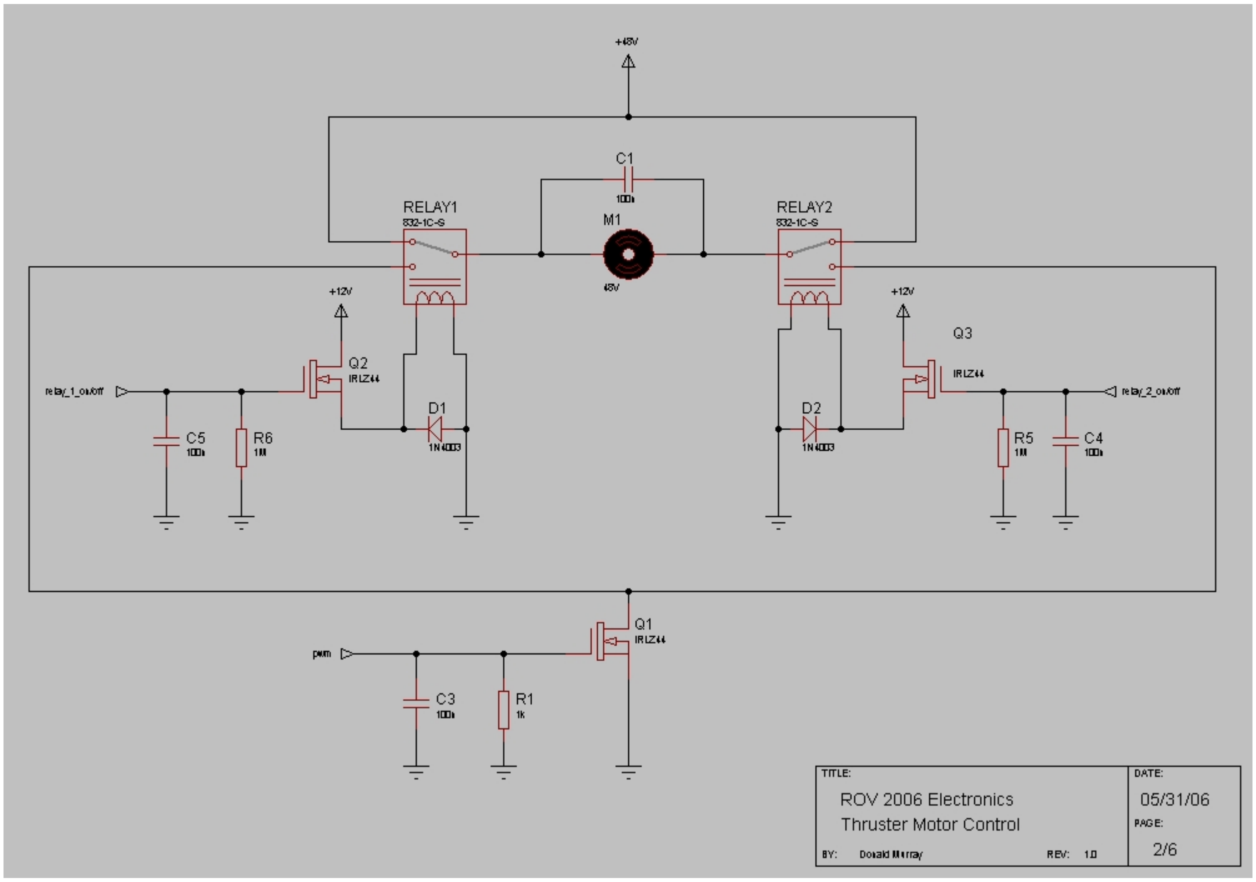

Figure 14: Thruster Circuit

Each of the four thruster motor circuits has two single-pole-double-throw relays, arranged as an H-bridge, and enabled by Rabbit output pins through a power MOSFET (Figure 14). The motor direction is selected by appropriate switching of these relays. Pulse width modulation switching is done through a low side power MOSFET. By changing the duty cycle on a PWM port, each thruster motor can be throttled up or down.

Stepper Motor:

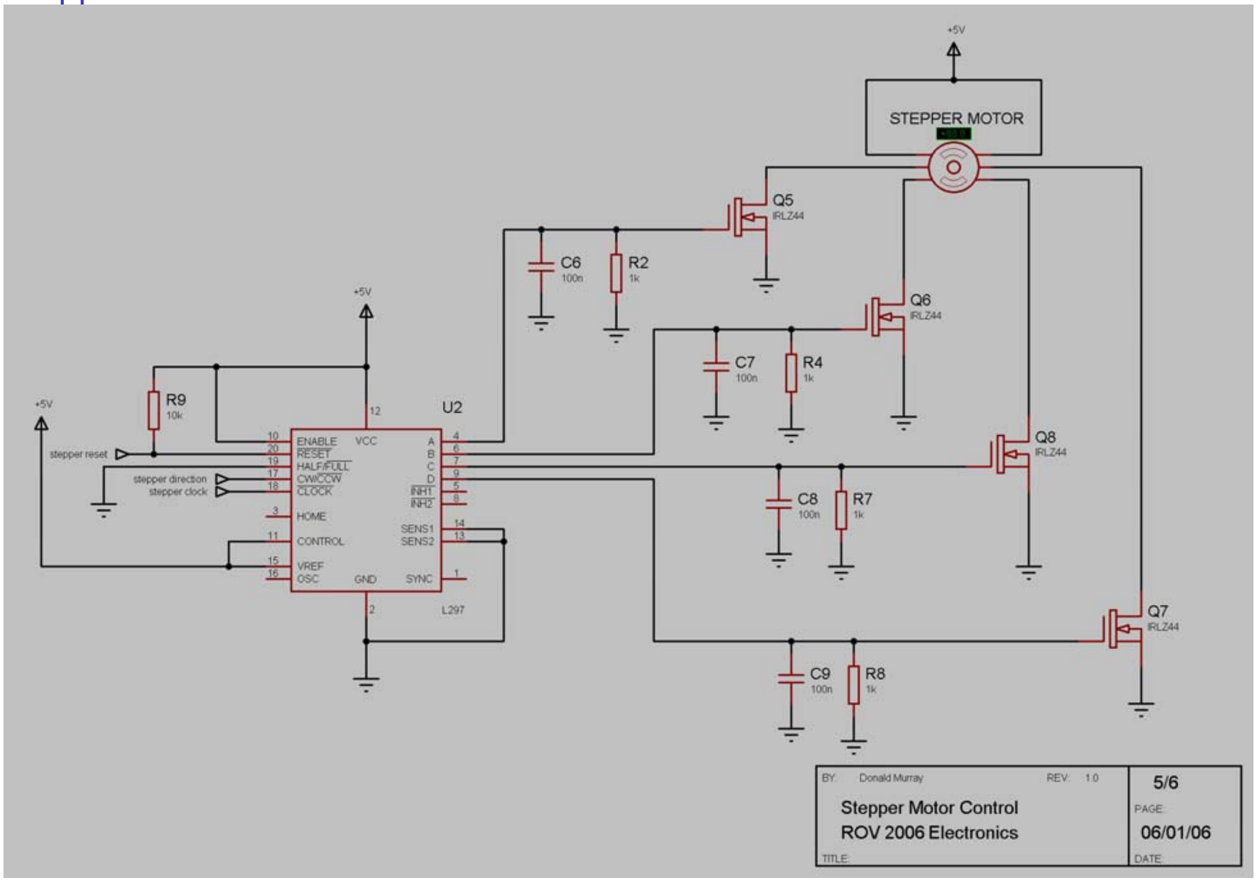

Figure 15: Stepper Motor Circuit

A provision for including a stepper motor for possible future expansion was included in the circuit (Figure 15).

Software:

The controller aspect of our vehicle is separated into two parts: a topside controller, used to interact with the navigator, and an ROV server, which performs the commands requested from the controller.

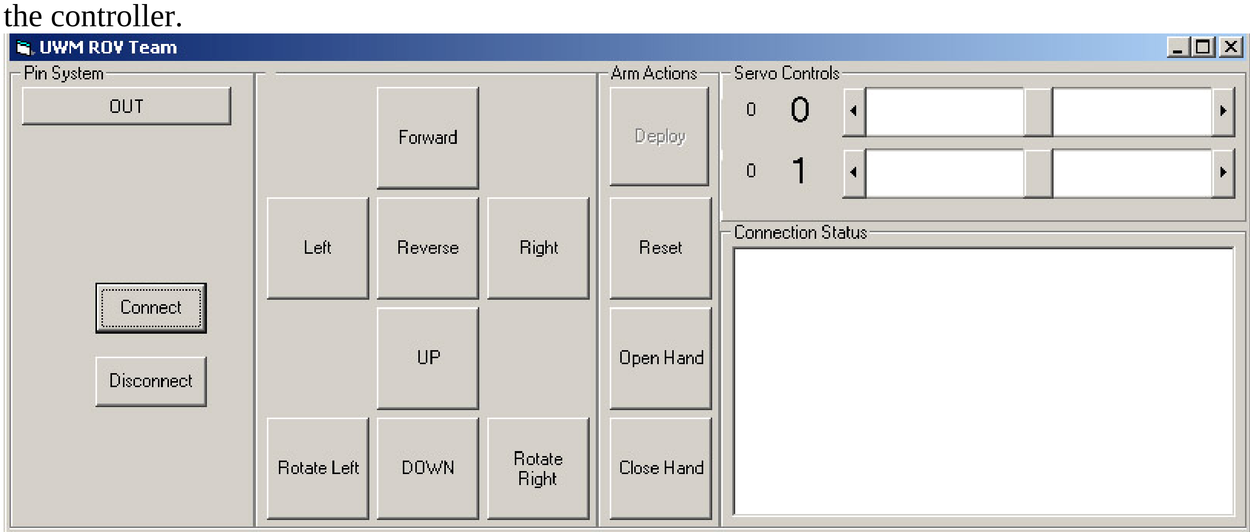

Figure 16: User Interface

The user interface of PantheROV II is written in Microsoft Visual Basic, which takes input from the keyboard and mouse of a laptop computer (Figure 16). The program was used because of its ease of development and debugging, and also because one could easily add an additional input device, such as a joystick. Command buttons control the motor and payload delivery system, and horizontal scrollbars control servo position for the camera.

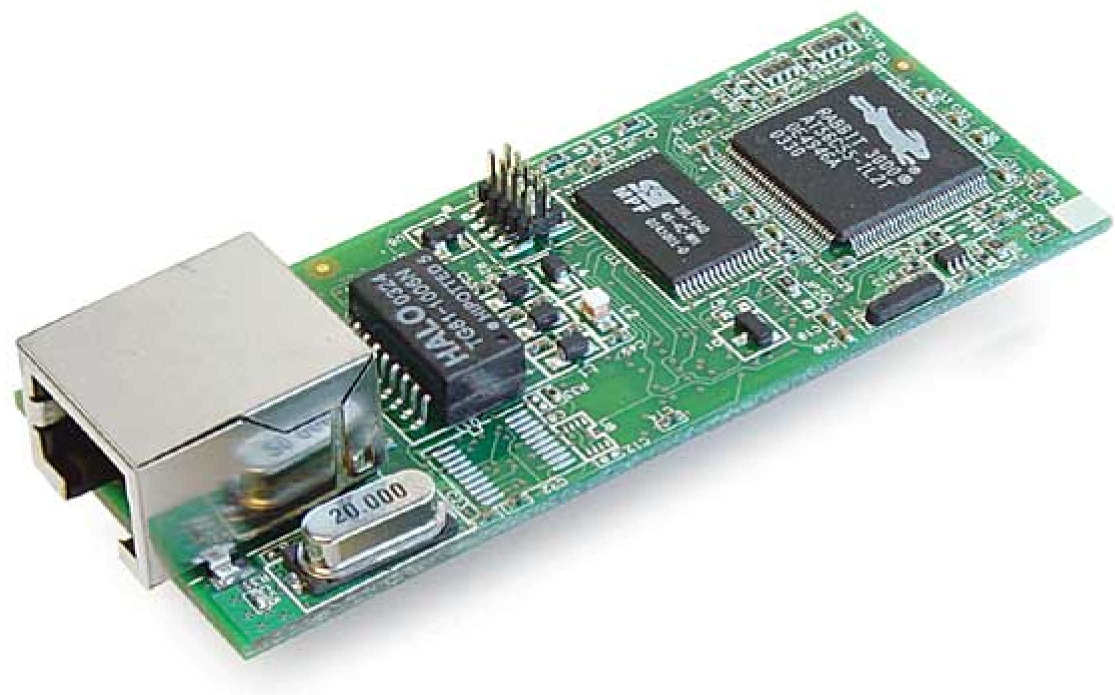

Figure 17: Rabbit Microprocessor

A Rabbit Semiconductor RCM3700 microcontroller is the onboard computer of the ROV (Figure 17). It was chosen because of its flexible design, which includes 31 digital input/output lines and an Ethernet connector. Some of the digital I/O lines can also be configured to be used as Pulse Width Modulation (PWM) ports and serial ports. To program the microcontroller, we used a programming language called Dynamic C on a PC. It is much like the standard C programming language, but it also includes libraries and keywords that are specific to the Rabbit hardware. In order to transfer the program to the RCM3700, it is “cross compiled” over a serial cable. The act of “cross compiling” is the process of converting machine code from one architecture to another.

The main communication line of PantheROV II is through Ethernet over a Category-5 shielded twisted-pair cable (Cat-5 STP). This method of communication is highly dependable and tested – It is the communication method of the Internet! In our application of Ethernet, we are using an Internet protocol called Transmission Control Protocol, or TCP. TCP is a connection-based protocol, which means that a connection must be established before commands can be sent. It has the advantage of having built in flow and congestion control, which prevents against losing packets of information. It also employs the use of acknowledgements and Cyclic Redundancy Check checksums (CRCs), which aid in detecting errors in the transmission. Through all of these safety features, we can assure that we have reliable command delivery, which can mean the difference between success and disaster.

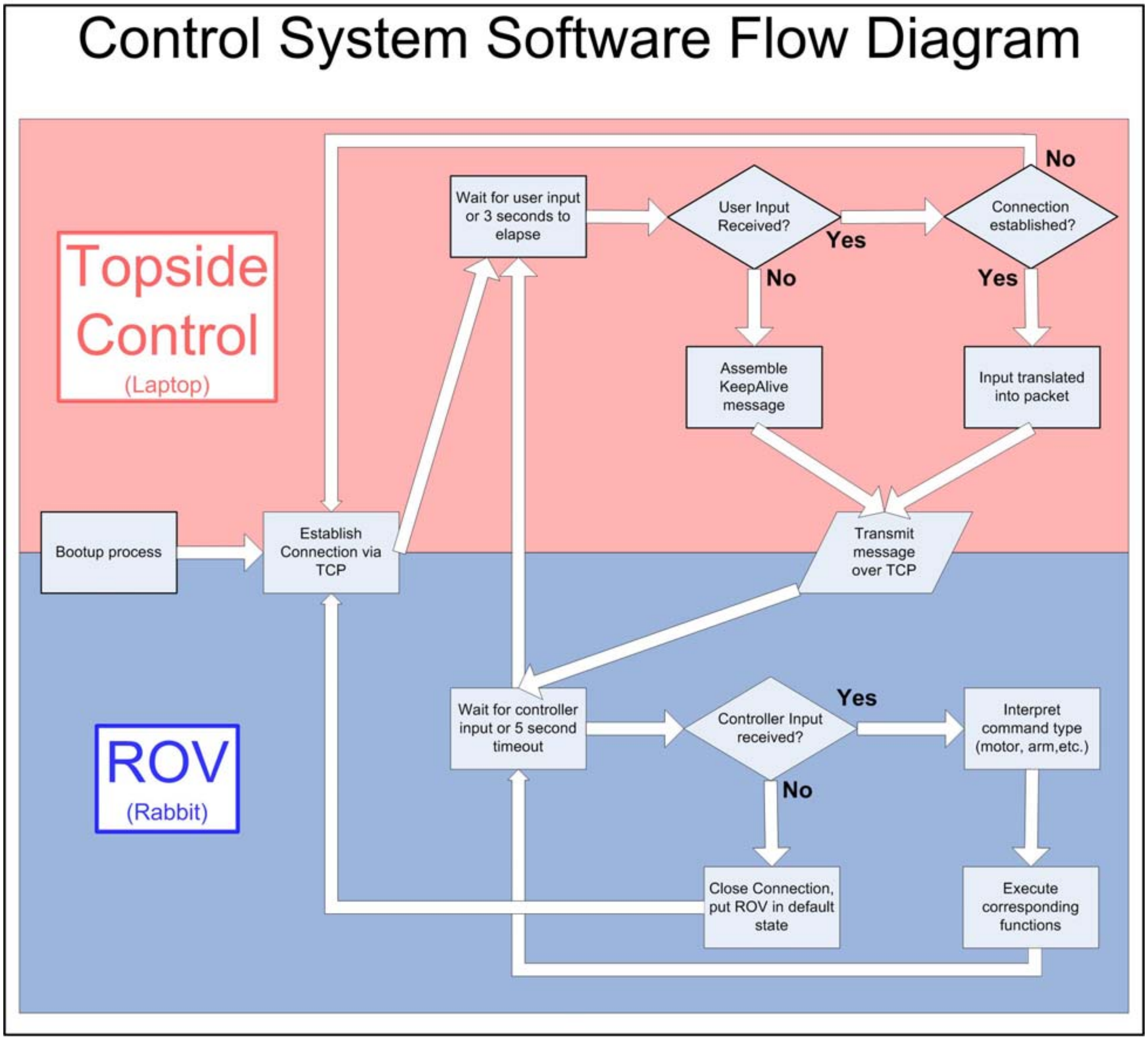

Figure 18: Software Flow Diagram

After the controller and the Rabbit boot up, a connection is made between the two (Figure 18). Following connection establishment, the navigator can begin sending commands to the ROV. In order to ensure that the connection remains established, a KeepAlive message flag is sent automatically from the controller to the ROV every 3 seconds. If a KeepAlive message is not received within 5 seconds, the ROV will return to a default mode and wait for a new connection to be established. This safeguard is in place so that if a disconnection occurs between the controller and the ROV momentarily, the ROV will not move uncontrollably through the water. If everything is functioning correctly, the Rabbit will receive a packet from the controller detailing the parameters of the four motors, the robotic arm, camera servos, and the payload delivery system. It uses an “If-Then” decision structure in an infinite loop to decide which functions need to be called to operate the ROV according to the commands issued by the controller.

Vision System:

The vision components are one of the unique aspects of our vehicle. We designed the system so that it has many viewing angles, because this is the only form of feedback we will receive when the ROV is in the pool. Another design goal is to create a tether that is thin and reliable. With four DLink DCS-900 Ethernet-enabled web cameras (6), we can accomplish our visual goals through 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 a connected computer, which uses software to reorganize the pictures into a motion picture.

One of our cameras is mounted inside the front of the hull, pointed out through a clear acrylic dome, and attached to two servos. These servos allow the camera to tilt and pan, giving us a 180-degree viewing angle. The other three cameras are each encased in a 76.2mm diameter acrylic tube and mounted on the outside of the vehicle (Figure 19). One end of the tube, where the camera lens is located, is fashioned with a clear polycarbonate faceplate for a flat viewing surface.

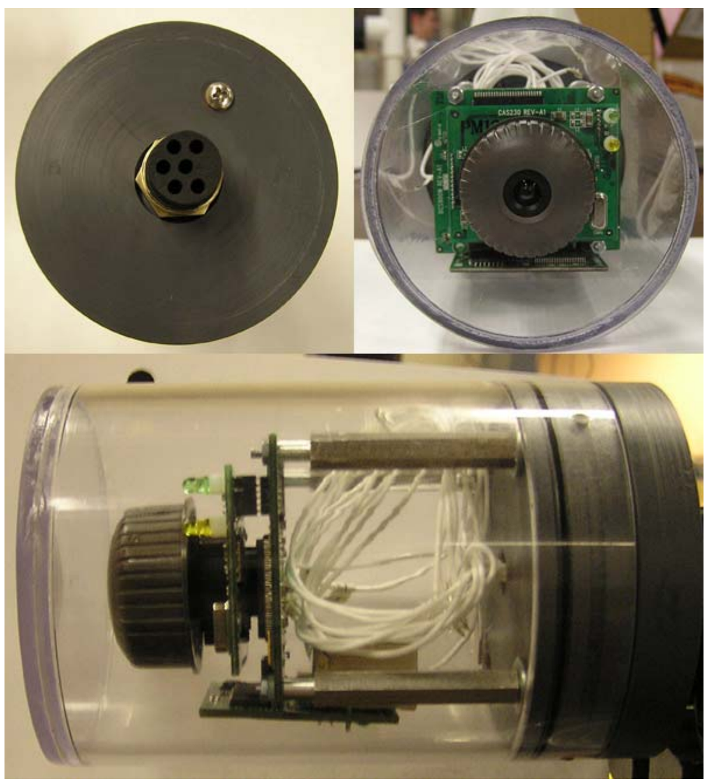

Figure 19: Camera Housings

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 connected to PantheROV II with an Impulse-constructed cable and is mounted to the PVC frame.

Troubleshooting

Although there is no one specific method that team members used to troubleshoot technical problems, we feel that the ability to troubleshoot and work out problems is one of the strongest suits of our team as a whole. This stems from the fact that we are all very good at catching problems in a system before the system becomes too large to debug quickly. This is done by dividing a design into its smallest possible building blocks, building and thoroughly testing each small block, and only integrating systems into larger blocks once the smaller ones have been exhaustively tested. Using this approach usually allows one to narrow down the location of a problem when it is discovered, and is generally much more efficient than testing a large systems only after all the smaller parts have been assembled.

Challenges

The greatest challenge that we faced was simply being able to function as a real team, with a single goal and organized plan of action. Since the entire team consists of college students with varying school and work schedules, simply having a regular weekly meeting that everyone can attend and work together during was impossible. A large amount of the communication between different team members was done by email, phone, or passing messages along from person to person. The resulting occasional communication breakdowns and seeming lack of organization (which is arguably inherent to any college club) resulted in some members leaving the club in frustration, and others who stayed in but were less motivated to really work on the project. We overcame this challenge by accomplishing large numbers of tasks during sudden bursts of productivity. These bursts came at the team meetings when the energy and enthusiasm in the room was especially high, and everyone in attendance was highly motivated to make real progress.

Lessons Learned

The most important lesson the team members learned was the importance of documenting every detail of the design, building, and testing process as these processes were taking place. Early on in the school year, as team members were beginning to experiment with possible designs for the individual systems, a lot of work with very useful results was done. However, the documentation of this work was sloppy and sporadic at best. Months later when we needed the data to make design decisions, it was difficult or impossible to locate most of it. Much of the work that had been done had to be repeated, and the second time around we were much better at recording important data as it was collected. Documentation is a critical part of the engineering process, but is barely touched on in a typical college curriculum. Our experience working on the ROV project has been a first hand lesson in the importance of integrating documentation directly into every phase of the engineering process.

Future Improvements

A flooded fairing would house the hull, and provides mounting points similar to a frame while being much more hydrodynamic, affording a much smoother and consistent flow. The thrusters and thruster cowlings would be integrated into the fairing, so the water is more efficiently directed providing more thrust. The fairing would be custom made by molding fiberglass over formed insulation board in two symmetric halves and then fiberglassed together for completeness and added strength.

GLUCOS

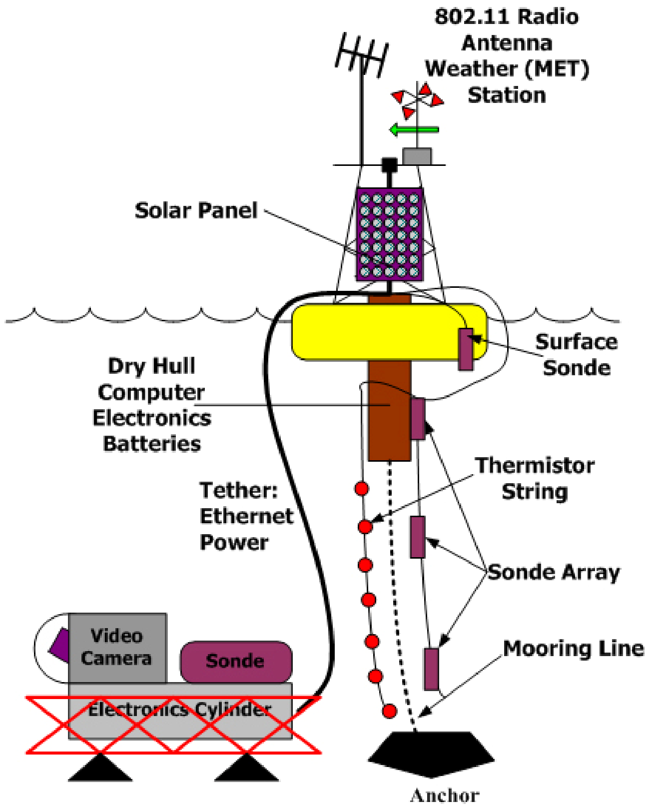

Figure 20: GLUCOS Buoy Layout

As student engineers at the Great Lakes Water Institute (GLWI) (7), we work daily with the issues involved with near shore underwater observation systems. We are in the process of developing and implementing Wisconsin's first lake observation system the Great Lakes Urban Coastal Observation System (GLUCOS) (8) (Figure 20).

The location of GLUCOS is the Milwaukee bight, a region Lake Michigan just east of Milwaukee, WI. This region is heavily impacted by the outlets of the Milwaukee, Menomonee, and Kinnickinnic rivers. The effects of these rivers on the Lake are currently studied by discrete sampling at relatively few points in both space and time. GLUCOS will permit continuous, long-term, sampling and sensing at many locations within the Milwaukee bight and thus greatly enhance our understanding of this dynamic and important freshwater system. Water scientists will be able to study numerous aspects of the effect on the bight and its general ecosystem.

Some of these research topics include:

- the “movement of pollutants, nutrients, sewage related bacteria and other anthropogenic inputs in the bight and out into the Lake” (9)
- “Impacts of invasive species on water quality and populations of existing aquatic species”
- “Relationships between meteorological conditions and lake chemistry and biology”
- “Changes in water quality related to continuing expansion of the metropolitan area.”

GLUCOS is comprised of up to 12 buoys networked with shore via radio modems. A central server located at the Great Lakes WATER Institute contacts the buoys and records data from the buoy’s many attached instruments including: ADCPs, digital temperature sensor strings, sondes, sediment traps, water samplers, and real time underwater video. With this array of devices we will be able to accomplish the scientific goals associated with the Milwaukee bight region mentioned above.

We can only hope that the vehicle being designed and built by our team will be able to be modified to become part of the GLUCOS system and help the scientists continue to do their job of collecting data to better our world’s underwater ecosystem.

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

Companies:
Impulse Enterprise, Inc.
IGUS, Inc.
Edmund Optics, Inc.
Bearings, Inc.

Individuals:
Russ Kutz-Techworks (www.techworksprogram.org)
Scott Kossow

References

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

(2) Chicago Rawhide (CF)
http://www2.chicago-rawhide.com

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

(4) Impulse Enterprise
8254 Ronson Road
San Diego, CA 92111
(800) 327-0971
http://www.impulse-ent.com/

(5) Express PCB
http://www.expresspcb.com

(6) 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/

(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/

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Budget

ROV Team @ UWM Expenditures				
Description	**Vendor**	**Quantity**	**Unit Price**	**Total**
Motor Couplings	Harbor Models Inc.	4	$10.95	$43.80
Waterproof Connectors	Impulse	1	$817.00	$817.00
12 Volt Car Battery	Wal-Mart	4	$71.05	$284.19
Pink Insulation	Home Depot	1	$10.56	$10.56
Electronics Module Materials	Jameco	1	$39.27	$39.27
Dlink DCS 900 Webcams	Buy.com	4	$82.99	$331.96
Linksys Ethernet Switch	Buy.com	4	$42.99	$171.96
Astro-40 Cobalt Motor	Astro Flight Inc.	1	$129.95	$129.95
203.2mm Aluminum Hull	Speedy Metals	1	$63.06	$63.06
Propellers	Harbor Models Inc.	4	$34.95	$139.80
Fiberglass Supplies	West Marine	1	$9.65	$9.65
Solenoids	American Science & Surplus	1	$11.62	$11.62
Motor Repair/Upgrades	Astro Flight Inc.	1	$95.00	$95.00
Main Camera Hardware	Home Depot	1	$12.61	$12.61
Mini Servo	Lynxmotion	1	$64.72	$64.72
Printed Circuit Board	ExpressPCB	2	$54.90	$109.80
Prototype Builder Board	Jameco	2	$14.99	$29.98
Transistors	Newark	20	$1.17	$23.40
Motor O-Rings	McMaster	1	$30.00	$30.00
Motor Bearings	McMaster	4	$5.74	$22.96
RCM3700	Rabbit Microcontroller	3	$49.00	$147.00
Capacitors	Newark	4	$11.59	$46.36
			Total:	$2,634.65

Note: The following products were kindly donated.

Description	**Vendor**	**Quantity**
177.8mm Acrylic Dome	Edmund	1
150" Shielded Twisted Pair	Igus	1
150" 4 Conductor 10 AWG	Igus	1
Astro-40 Cobalt Motor	WATER Institute	3
Various Raw Materials	WATER Institute	N/A
Shaft Seals	Bearings Inc.	5

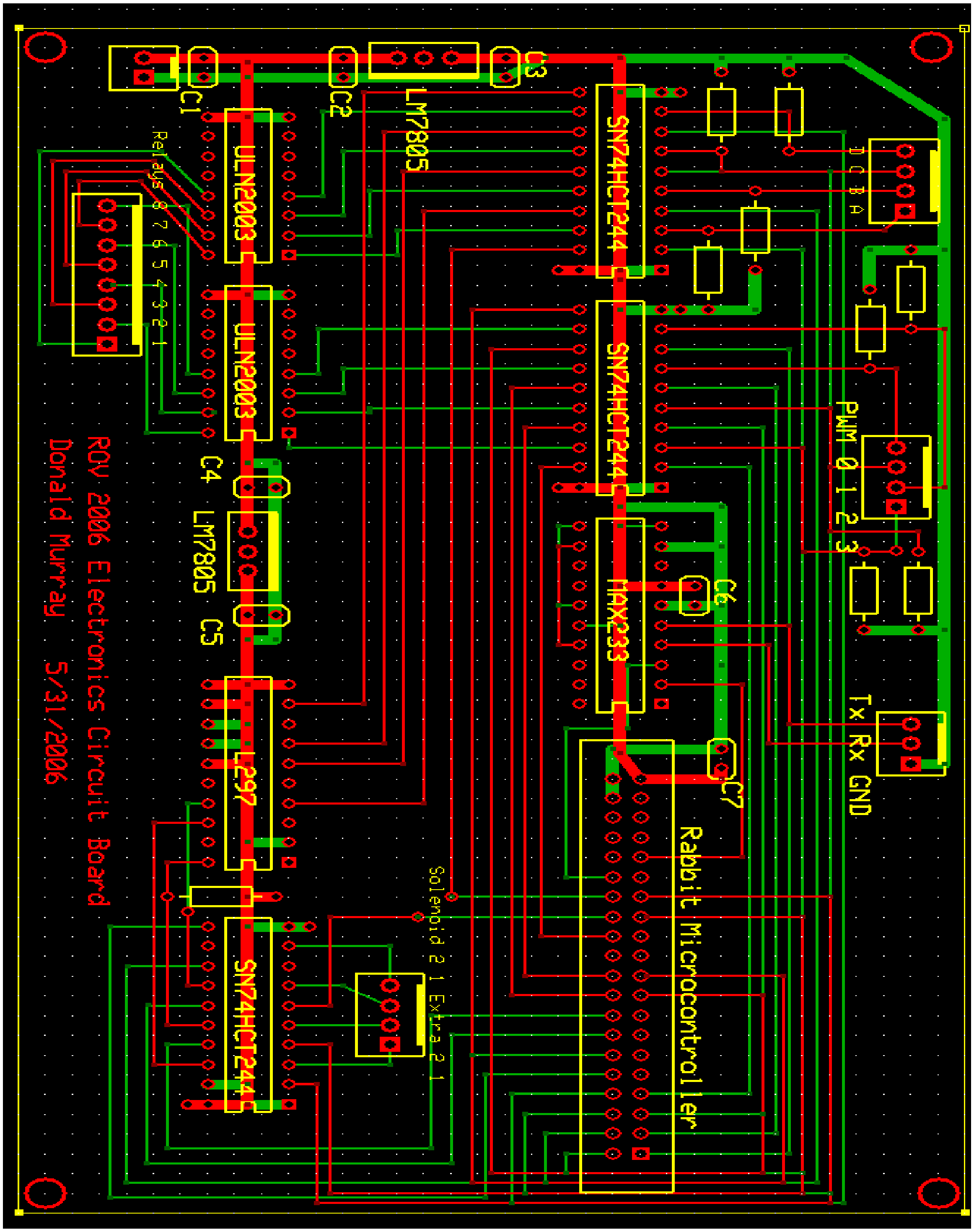

Figure 21: Express PCB Board Layout