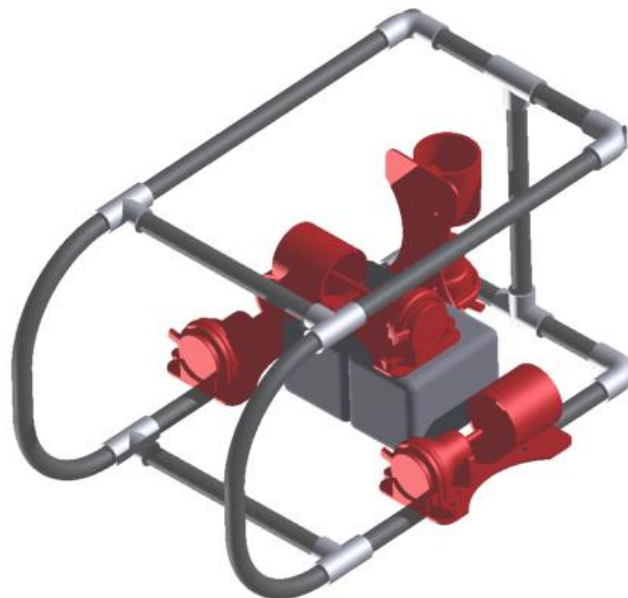


# BCIT

# ROV TEAM



BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY



Team Members:

Karl Lepic  
Colin Lockwood  
Colin Martin  
Derek Richards  
Samson Suen  
Billy Tong

Instructor:

Taco Niet

Other Sponsors



## **ABSTRACT**

A robust and versatile underwater ROV, capable of enduring harsh arctic environments and the unrelenting open ocean is required by today's scientists and engineers to explore a vast unknown underwater world and serve as a workhorse. A young team of six BCIT (British Columbia Institute of Technology) mechanical design students was formed to design and construct this ROV. The ROV uses an exoskeletal frame to keep all the ROV internals safe from the crush power of arctic ice, at the same time providing positive buoyancy. Four thrusters are used to rotate the ROV around its vertical axis, control its depth and power its way through strong ocean currents. A buoyancy compensation system was implemented to keep the vessel stable and neutrally buoyant when carrying different payloads. Both passive and active tools are used to complete the missions outlined by MATE. The mixture of passive and active tools greatly simplified the controls of the ROV. Controlling the ROV is done with a single computer gaming joystick to make the controls for the pilot comfortable and simple.

## **ACKNOWLEDGEMENTS**

The BCIT ROV Team would like to thank you BCIT for being the main support for this project. Special thanks to all the instructors for their time and effort. Also, they like to thanks International Submarine Engineering Ltd. and Oceanworks International for their financial support. Last but not least, the team would like to thanks MATE their financial support and for being the host of the competition

## INTRODUCTION

The miseries and the wonders in the frigid waters of the arctic still baffle mankind. “What secrets, what clues to the planet’s past, lie under the ice? How does life survive extreme cold and long dark?” [1]. The only way to answer some of these questions is to venture into the cold of the arctic.

The organisms under the thick ice sheet are like no other in the world. It is a great opportunity for scientists to have a chance collect live samples under the ice to gather a greater understanding of the arctic environment. Other than life, under those hostile waters are vast pockets of oil reserves. With the world hunger for oil, the ability to tap those resources is paramount. Sending people in those waters is far too hazardous but our team has constructed a ROV that can do those tasks without risking lives.

To emphasize the significance of ROV in the field of science and research, MATE is hosting a competition to promote the idea to students in the industry. The 2007 MATE ROV competition was designed in recognition of the International Polar Year (IPY). IPY first started in 1882-83 in an effort to learn more about meteorological and geophysical phenomena that are affected near the earth’s poles. The research involved 12 countries in 15 different expeditions. Since the first IPY, two similar research efforts have been completed resulting in major discoveries in meteorology, magnetism, radio science and geophysics. In 1957-58 the theory of continental drift was proven and the first satellites were launched. Another IPY has been assembled for 2007-08 to research issues and variables affecting the atmosphere, snow and ice, landmass, ocean ecosystem and people. Figure 1 shows a photo of an IPY station located in the arctic. [2]

The BCIT ROV Team was established in January 2007 to compete in the upcoming MATE ROV competition. The team consists of six Mechanical Engineering Design students, each in their final year of their technology diploma. BCIT hopes to have future ROV projects. With the achievements and experience gathered from this year team, BCIT hopes that those will bring success to future teams. The team is grateful to participate in the competition and its team members are excited to explore opportunities in the marine industry.



**Figure 1: Arctic station**

## DESIGN RATIONEL/VEHICLE SYSTEM

### *Chassis*

Variables such as material and shape had to be taken into consideration when the design of the chassis began.

#### *Material*

The chassis of the ROV needs to be constructed out of material strong enough to withstand the weight of the components yet light enough to be positively buoyant. Having positive buoyancy makes the overall stability of the vehicle easier to achieve. Other factors such as sensitivity to cold temperatures, availability, and ease of assembly were also considered. Different material shapes were also considered. After many considerations polyvinyl chloride (PVC) piping was chosen for its relative strength and low weight. The piping may also serve as positive buoyancy once it is sealed. In addition, PVC piping and fittings are readily available through local supply stores, easy to assemble, and relatively inexpensive. Also, PVC is not affected by environmental elements such as temperature and corrosion in which the ROV will be operating in.

#### *Shape and Sizing*

The structure of the ROV itself was modeled on the principle of simplicity and functionality. A standard cube shape was chosen as a platform for our chassis design for ease of manufacturing and component mounting.

Initially, the chassis was design to maximize the internal space for mounting the components while still small enough to meet the competition restriction. For the first design, the chassis was specified to be 70cm × 70cm × 80cm with the pipes specified at 2in (50.8cm) diameter. This was done to allow maximum internal space inside the frame, while meeting the criteria to fit through the hole for the ice tank mission. Large diameter piping would ensure positive buoyancy and maximize strength.

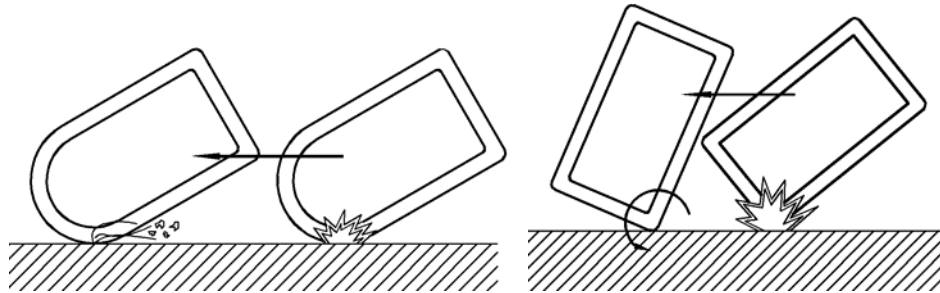
After analyzing a mockup for one of the designs, it was realized that the dimensions were too large. The immense size of this design would result in poor mobility and create difficulty when deploying and retrieving the machine.

The initial design was refined and a final design was created. The final frame design was



**Figure 2: Final frame design**

constructed of ½in (12.7mm) PVC conduit and connected by standard fittings. The weight and drag was reduced significantly by using smaller diameter pipe while the robustness was not significantly reduced. As shown in figure 2, the front portion of the frame incorporated a curve. Initially, it was planned to have the conduit bend to form one continuous arc to create a skidding affect on the bottom of the tank (shown in figure 3 and 4). Bending was deemed too difficult and unnecessary as the pipe cross-section was very small and may have collapsed. Pre-fabricated 90° bends were used instead thus offering the same geometry for fraction of the build time.



**Figure 3a (left):** When the vehicle hits the bottom of the tank, the round allows the vehicle to skid  
**Figure 3b (right):** When the vehicle hits the bottom, the sharp corner may cause the vehicle to roll

### ***Thruster Placement/Design***

The main requirements of the thrusters were to propel the ROV through the water with sufficient thrust to overcome the current in the flume tank and draw a maximum of 5amps, per thruster, at any given time.

The overall layout of the propulsion system uses a four-unit drive system. The placement of these four thrusters gave the ROV ability to move in all three planes and rotate around the vertical axis.

Two thrusters mounted on the port and starboard sides of the ROV for fore and aft motion. By reversing the polarity one motor, the ROV may rotate around the vertical axis for skid steering. The skid steer allowed the operator to position the manipulators as needed for each scenario. Although the four-unit design has limit some of the maneuverability of the ROV, the addition of thrusters to control pitch and roll were considered unneeded and removed to simplify the operating system.

The final propulsion design incorporated a simple, inline drive concept that was easy to manufacture. The propeller was mounted on a shaft inline with the motor thus reducing flow obstruction. The deflection and propeller obstruction compromised each other thus a final shaft length of 65cm was used. The port and starboard thrusters were mounted such that it maximized forward thrust since reversed thrust would mostly be used for corrective action.

The design used an 800 GPH (3030 L/min) modified sealed motor unit from a Rule<sup>®</sup> sump pump. The motor required minimal modification and is relatively cheap and reliable. The motor design was chosen with three considerations:

1. Maximum per unit draw at roughly 5 amp
2. Thrust produced with different propellers
3. Waterproofing.

Working in conjunction of the controls design, a 5 amp per motor limit was chosen. This limit allowed for a maximum worst case draw of 25 amps for the thrusters and manipulators leaving 5 amps to control other on-board devices.

Thrusters were tested in combination with different propeller to find the optimal performance. A maximum thrust of 9.43 N at 5 amps using a three-blade propeller was tested. A more powerful motor was not selected since it would draw more current.

With the motor selected, the design was adapted to include a shroud. The shroud, although basic in design, help direct all flow through the propeller and ensure the water exits as thrust. Pre-manufactured pipe was machined to closely enclose the propeller. The thruster assembly was mounted on an acrylic plate such that it may be removed or adjusted with ease. Rubber was used between components to reduce vibration transfer between the thruster and ROV. One of the feature went into the design was to have the thruster unit assembled into a compact module. This will make mounting easy and when a unit malfunctions, the module will be replaced instead of individual parts. The thruster assembly was mounted to the frame using ½ in (12.7mm) pipe clamps.

### ***Buoyancy/Stability***

An excel spreadsheet template (A-5) was created to calculate the sum of the buoyant force acting on the ROV. The spreadsheet calculations were created based on the Archimedes' equation. Using a spreadsheet allowed the team to optimize the weight and buoyancy distribution prior to testing. Material properties were used to calculate the weight of each component in water. Once the spreadsheet was complete, the buoyancy package was designed.

The design of the floating body required the use of lightweight materials that offered a high degree of buoyancy. In addition, when a relatively heavy object must be moved while submerged in a fluid, it is often desirable to add buoyancy to facilitate mobility. The buoyancy material should typically have the following properties:

- Low specific weight and density
- Little or no tendency to absorb fluid
- Compatibility with the working fluid
- Ability to be formed
- Abrasion resistant and durable

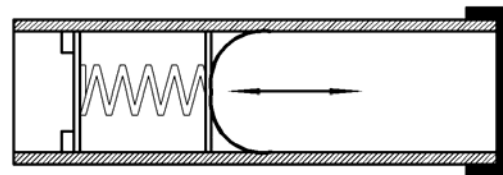
For those reasons a foam pack was chosen used for the ROV as buoyancy material. Since foam is a continuous network of closed, hollow cells that contain air other lights gases, it ensured a high buoyancy force and low absorption.

To deal with the payload for each mission, a few designs for a mechanism which would compensate for the weight change were developed. The heaviest payload the vehicle needs to carry is the PAS in mission 2, which weigh about 4N under water. For that reason, all designs were based on the 4N value. The designs are based on the concept of varying the size of a enclose volume to change the buoyancy of the ROV.

The first design was based on a piston-cylinder mechanism. As the piston moves along the length of the cylinder, there would be a change in the volume, creating a change of buoyancy. The buoyancy will change to compensate for the payload. This design was not used because there was not a simple and reliable means of moving the piston.

The second design uses a cup attached to the ROV, hanging form pivot, while the payload attach to the open end. An air bubble would be trap inside the cylinder as the ROV enters the water to increase the buoyancy of the ROV. When the payload is released, it would actuate a mechanism to flip the cylinder around the pivot, upside down to release the air bubble. The buoyancy would decrease when the air bubble is released to compensate the decrease in weight. This design was not used because of the difficulty involved designing the mechanism to flip the cup.

The final design (Figure 5) is similar to the first one, but instead of using a piston to change the volume, a diaphragm and a spring is used. The retracted spring and diaphragm would create a set volume. When the payload is released it will actuate a catch mechanism to release the spring and diaphragm, there would be a change in volume, creating a change of buoyancy.



**Figure 5: Diaphragm ballast**

### ***Manipulators***

A number of special purpose manipulator was designed to perform all the mission tasks.

#### *Messenger Line Threader*

To complete the task of threading the messenger line through the buoy anchor the tool had to be lightweight, compact, removable and be able to complete the task quickly. In order to meet these criteria the tool was made completely mechanical and passive. Having no electronic aid in threading the line through the anchor allowed the pilot to

focus on lining up the tool rather than operating it. The design allowed for the pilot to maneuver the ROV up to the anchor without great accuracy due to the large mouth on the end of the tool and plow forward to set off the two triggers, back out and re-surface. The tool was made out of aluminum to keep weight down and still remain strong. Brass was used to reduce friction between the aluminum parts and allow for smooth operation. Stainless fasteners were used to prevent corrosion. The messenger line threader was mounted to the ROV using PVC U-clamps and an aluminum bar to add torsional stiffness and prevent rotation.

### *Suction Unit*

Instead of trying to grab the algae sample (ping-pong ball) from under the ice surface, the ROV uses suction to collect a ping-pong ball into a storage chamber. The suction unit consists of a bilge pump, collection tube and funnel. The bilge pump uses was a 600 GPH (2270 L/min) SeaSense®. The pump ran at 12 volts drawing 3 amps at operating loads. The collection tube was made of clear acrylic tubing with an inner diameter of 50.8mm. A clear tube is used so the pilot could confirm that a sample of algae was secure before shutting off the bilge pump. The collection tube had two counter-return springs, which allowed the ping-pong ball to travel down the tube but would stop the ball from floating out. The funnel is used to give the suction unit a wider spread, even though the funnel reduces the effectiveness of the suction unit it was deemed necessary, as piloting the ROV directly beneath an algae sample may very difficult.

### *Gasket Installer*

The gasket installer is designed to mount underneath the ROV. A guiding funnel was added to the design to allow the pilot to guide the mechanism overtop of the wellhead. The mechanism is actuates as a result of the wellhead being pushed up into the actuator disc thus moving a tab mount upwards with respect to the gasket. The holding tabs were then bent up causing the gasket to free itself from the mechanism. The gasket pusher is fixed to the ROV and provides a solid body for the gasket to be clamped against. Three sliding posts provide stability for the mechanism and guide springs that keep the device normally closed.

### *Robotic Hand*

The robotic hand was designed specifically so that it may pick up the o-ball in Mission #2 and lift off the wellhead cover in Mission #3. It was roughly 290mm in length (hand closed) and 105mm wide across the hand. The hand was mounted sideways on the front of the ROV.

The robotic hand was comprised of the drive, power screw, four bar linkage and hand.

### 1. Drive

The drive consisted of a 12V DC motor and a 1:3.33 planetary gear reducer. The motor was taken from a 600 GPH (2270 L/min) SeaSense<sup>®</sup> bilge pump. This particular motor was chosen since the manufacturer had already sealed it. The gear reducer was chosen to reduce the motor speed from 4000 RPM to about 1200 RPM and increase the torque applied to the power screw.

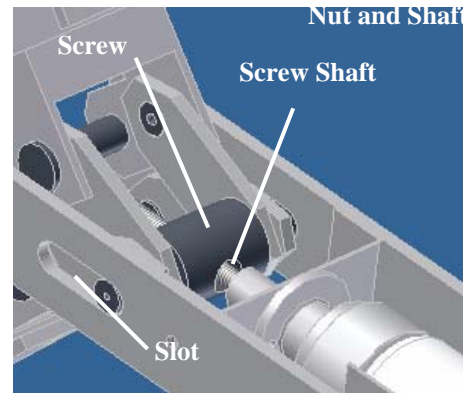


Figure 5: Power Screw

### 2. Power Screw

The power screw was designed to transfer rotational motion from the motor into fore and aft motion in the four bar linkage. The power requirements were determined such that the power screw would fully open or close the hand in 2 seconds and exert a load of 25 N to the four bar linkage. A torque of 0.083 N-m was therefore required.

The screw nut was comprised of a PVC shaft, which moves along a slot thus keeping the nut aligned and protecting from damage in case of collision. The actual threaded nut is pressed inside the PVC shaft. The shaft was made of stainless steel ready-rod and was coupled to the motor shaft. The power screw used an M5 x 0.8 thread and was designed to be self locking thus the motor would not need to be engaged when holding onto an object. A friction factor between the two materials was assumed to be 0.25.

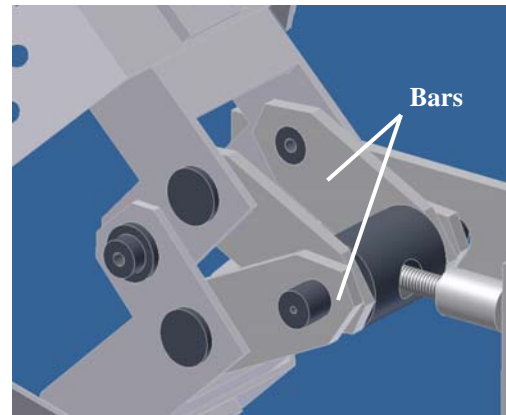


Figure 6: Four Bar Linkage

### 3. Four Bar Linkage

The four bar linkage system was designed to push and pull the hand open and closed. This linkage was chosen in this design for simplicity and reliability.

Each bar was designed to use 3.31mm thick 12.7mm wide standard 6061-T6 aluminum bar. The ratio of force applied

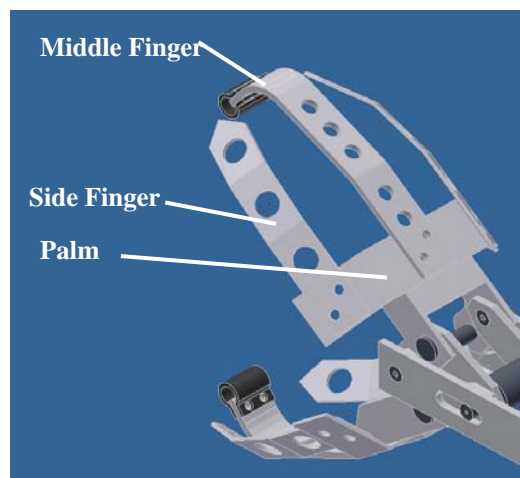


Figure 7: Hand

to the linkage by the power screw and the force at the tips of fingers was calculated to be about 1:14. Although this ratio required a lot more torque than other possible designs considered, it allowed the linkage to produce a lot of hand movement from a small amount of movement in the linkage thus saving space.

#### 4. Hand

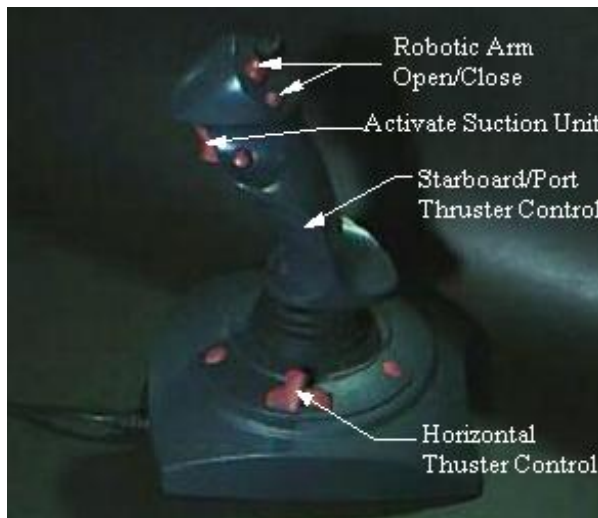
The size and overall shape was determined by the size of the o-ball in mission two. Fully extended, the hand opened 247mm thus allowing the pilot of the ROV to easily grab the o-ball in mission two. The tips of the middle fingers were designed to meet flat such that it would be easy to lift and hold the wellhead cover in mission three.

The side and middle fingers were mounted to the palm made of 12ga. Aluminum sheet. The side fingers were also made of 12ga. aluminum sheet, as structural strength was not a large issue. The middle fingers however were required to hold the forces applied by the power screw and thus were made of 1/8" aluminum bar. Rubber tips were added to the middle fingers for extra grip.

The material selection was very important in the design as the tool would be subjected to a corrosive environment. Aluminum was chosen for its lightweight, low corrosive properties in water and machinability. PVC plastic was selected for the pivot shafts and bushings for its relatively low coefficient of friction, high strength and machinability.

#### *Electrical/Controls System*

Since the pilot has to maneuver the ROV and perform mission tasks at the same time, such as collecting the algae sample and jellyfish, it was deemed necessary to make the controls as easy to operate as possible. The pilot would use a joystick to control the speed and direction of the port and starboard thrusters and two sliders to control the speed and direction of the vertical and horizontal thrusters.



**Figure 7: Pilot's joystick**

Designing a control system for the ROV presented the team with a unique problem; the team was comprised of mechanical design students with limited experience with electrical circuitry. Even though inexperienced in computer programming and circuitry the team decided that a microcontroller-based system would give the pilot the best control over the ROV.

The team decided to use microcontrollers to control the ROV. One microcontroller was located in the pilot controls at the surface,

the second on the control circuitry onboard the ROV. The pilot may control the ROV with inputs from a joystick (Figure 7). The joystick had four potentiometers (POT); each POT control one axis of the ROV's movement. The POTs were connected to the Analog to Digital Conversion (ADC) ports on the topside micro controller. The topside microcontroller takes the ADC values and sends them down the tether to the bottom side microcontroller. The bottom side microcontroller takes this information and set the direction and speed of the individual thruster motors. The ROV uses H-Bridge circuits to change the polarity of the thruster motor, changing their direction or rotation. To make the controls as compact and easy to make the team used a high current integrated h-bridge circuit manufactured by Pololu. Each thruster requires one H-bridge circuit. Pulse Width Modulation (PWM) is used to vary the speed of the motors by pulsing a signal to a transistor in the H-bridge circuitry. This transistor turns on and off the supply voltage to the motors. Pulsing the supply voltage varies the average voltage to the motor, thus the rpm of the motor is modulated. The bottom side controls for the ROV has the ability to control four bi-directional motors with PWM for the thruster motors, one bi-directional motor for the robotic arm and one on/off motor for the suction unit. Along with control of the motors the microcontroller has to be able to receive the serial signal from the topside microcontroller; to satisfy these requirements, the ATmega32 microcontroller was used.

Both topside and bottom side microcontrollers were programmed using the C programming language. C was used because it is one of few programming languages used to program firmware. C was not the easiest program to learn but it proved to be very powerful. Programming of the topside controller was completed, however the bottom side controller code is still being developed.

### *Miscellaneous*

#### *Tether*

Since onboard power was being used the size of the tether was reduced significantly. CAT 5e was used as a signal because it was readily available and relatively small in diameter, which is a very important consideration when designing a tether. The CAT 5e tether had a secondary support line, which was slightly shorter than the CAT 5e cable. The purpose of this secondary line was to prevent damage to the signal line or to its connections in the event the ROV had to be pulled out of the water. The support line was 1/8 inch Spectra® line. Spectra® line was selected because it is close neutral buoyancy.

#### *Cameras/Video*

MATE rules and regulations allow the use of three monitors in the pilot booths and the BCIT ROV Team took advantage of this. One stationary camera and



**Figure 8: CVC 320-WP underwater video camera [3]**

one removable camera with multiple mounting points were used on the ROV. Each camera displays a video onto one of the three monitors. The ability to view the underwater environment from many different angles was deemed crucial for the success of the missions. One fixed, forward mounted, color video camera gave the pilot an 80° field of view directly in front of the ROV. The two movable cameras were used to give the pilot views of the different tools mounted on the ROV. The cameras were moved to different positions depending on which tool was being used. The cameras used on the ROV were water proof (up to 15 meters) and have been purged with nitrogen. Purging the cameras with nitrogen prevented any condensation on the lenses while the ROV operated in cold water conditions. One black and white cameras were utilized. A ring of infrared LEDs around the camera lens (Figure 8) allowed for better viewing in low and no light conditions.

### *Lights*

The main light source for the black and white cameras came from the infrared LEDs mounted inside the camera housing. These LEDs provided a sufficient amount of luminous around the view of the camera. For the color camera and general light, white colored 20000mcd LEDs were mounted in the front of the ROV. Each LED had a projection angle of about 20°. With 10 mounted in a row sufficient lighting was provided.

## **CHALLENGES**

The largest challenge was the design of the control system. The BCIT ROV team consists only of mechanical students with very limited knowledge of computer programming and electrical controls. Even with this consideration micro controllers were used thus a lot of research was done to learn C programming, micro controllers and circuitry components such as electric motor drivers.

Another large challenge was finding a means of waterproofing the electric motors used for the thrusters and manipulators. Bilge pump motors were used for their off the shelf simplicity and reliability.

## **TROUBLESHOOTING TECHNIQUES**

The controls of the ROV were very tedious to troubleshoot. A breadboard was wired to the micro controller with LED's to represent thrusters, suction unit and robotic hand. The program was adjusted until the desired outputs were reached. To troubleshoot the manipulators trial and error was used.

## **LESSONS LEARNED AND FUTURE IMPROVEMENT**

One of the main issues we faced was time management. It was difficult to allocate time for this project when juggling the school schedule at the same time. A solution to this problem would be to make an accurate project schedule and appoint a project manager for the team.

For future projects, it would also be desirable to research and apply Kort nozzles to the thruster designs. The increase of thrust by the nozzles will decrease the size of the motor needed. The smaller motor will weight less and demand a smaller current draw.

## **REFLECTIONS**

This ROV project was an excellent learning experience for students as they need to apply all the knowledge they acquired from school to this project. Also, having the opportunity to manage this project from beginning to end shows the students what it takes to complete project at this scale.

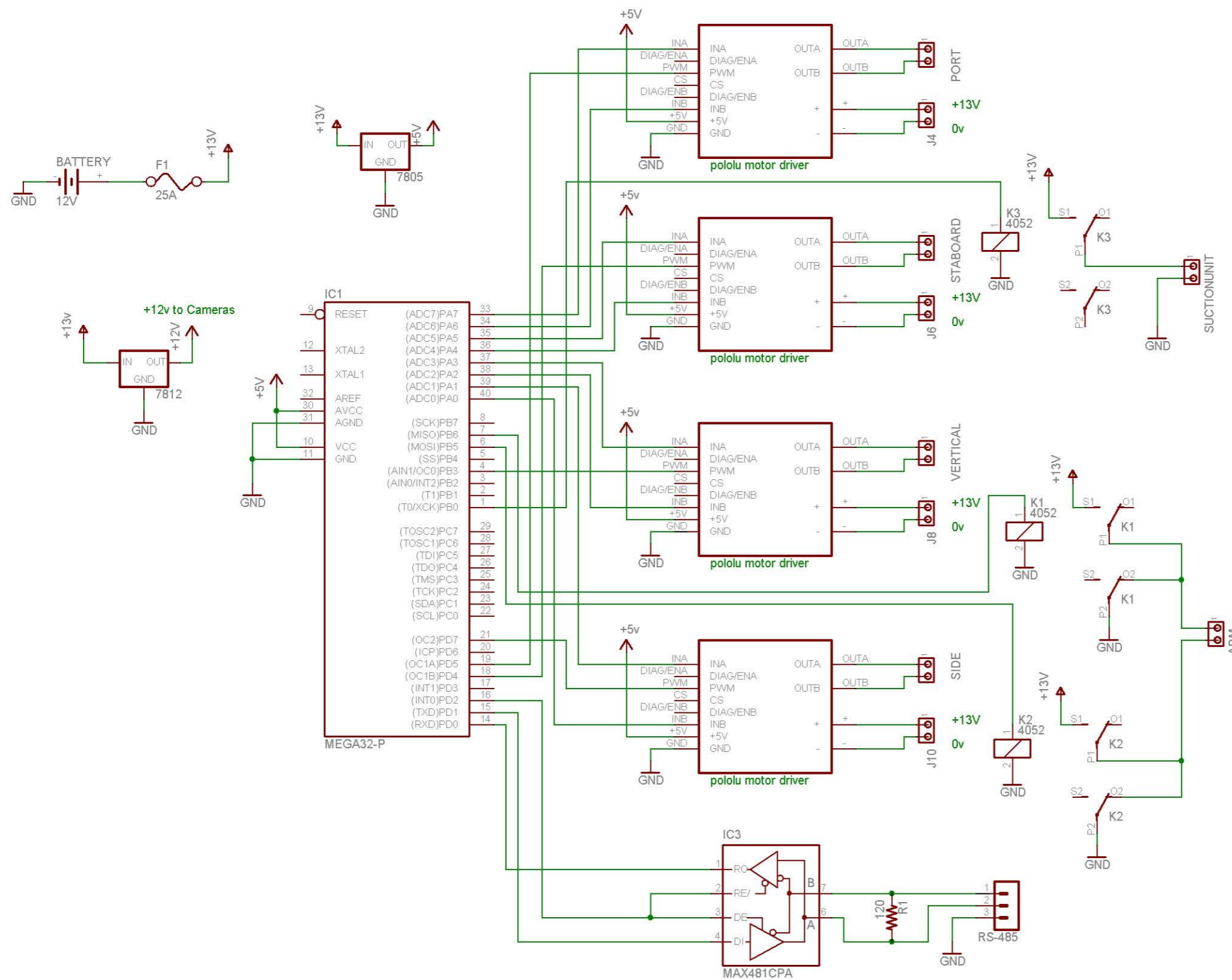
This is the first ROV team out of BCIT to participate in this competition. The team hopes that they do well in this competition and set a good stepping stone for future projects. Future BCIT teams will take the lessons learned for this project and apply them to future competitions.

## **CONCLUSION**

Designing this ROV was a great learning experience. The team hopes that the knowledge they gained will be passed down to future BCIT ROV teams. The team is excited to be a part of this competition and is looking forward to be in St. John, Newfoundland and represent BCIT at the competition.

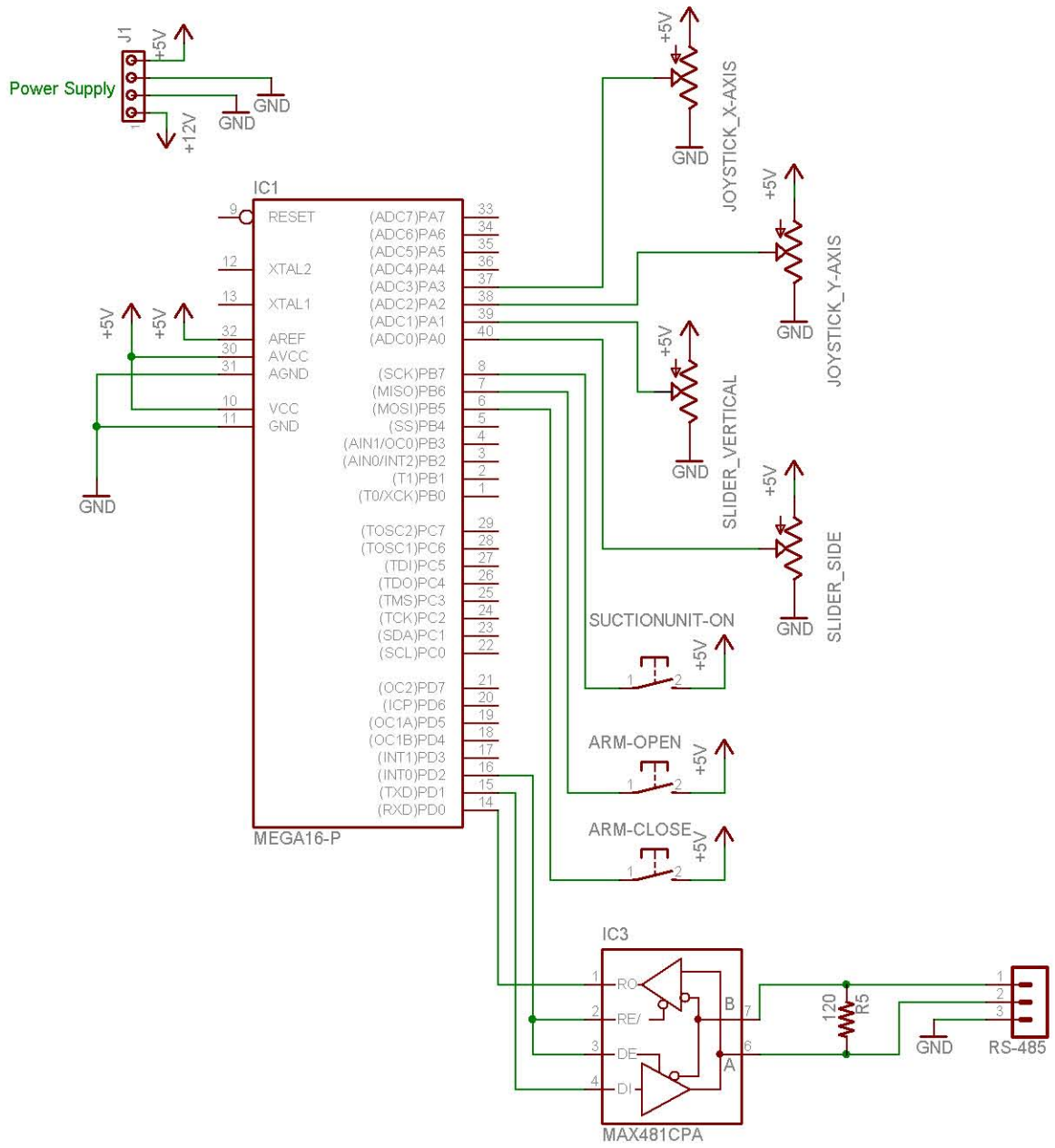
## REFERENCES

- [1] IPY International Programme Office, *International Polar Year 2007*, <http://www.ipy.org/> (June 1<sup>st</sup>, 2007)
- [2] The University Centre in Svalbard, *UNIS and the IPY 2007*, <http://www.unis.no/ipy/> (May 31<sup>st</sup>, 2007)
- [3] *Specotechnology*, [www.specotech.com](http://www.specotech.com) (May 31, 2007)



BCIT ROV Team	
TITLE: BottomSide	
Document Number:	REV:
Date: 01/06/2007 04:57:10p	Sheet: 1/1

# Appendix - 2



**BCIT ROV Team**

**TITLE: TopSide**

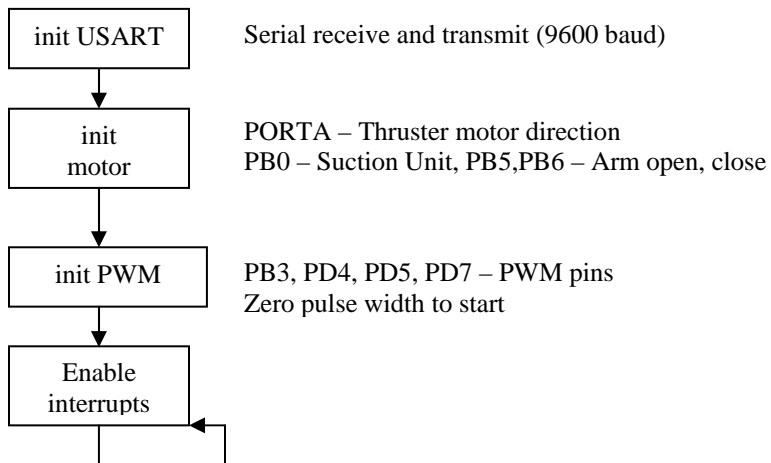
<b>Document Number:</b>	<b>REV:</b>
-------------------------	-------------

<b>Date: 01/06/2007 04:57:32p</b>	<b>Sheet: 1/1</b>
-----------------------------------	-------------------

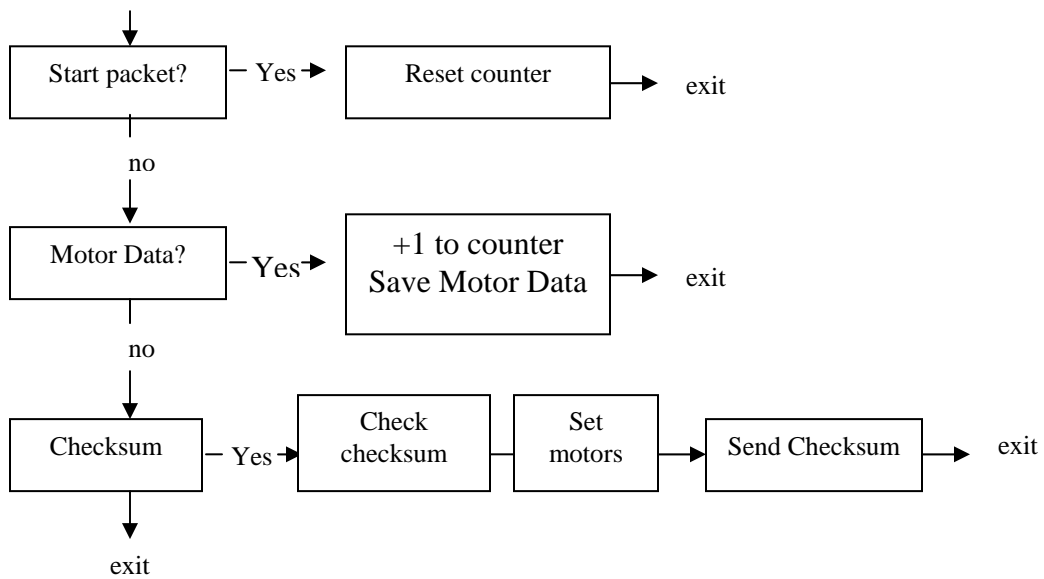
### Appendix 3

### Bottomside Control Flow Chart

#### Main



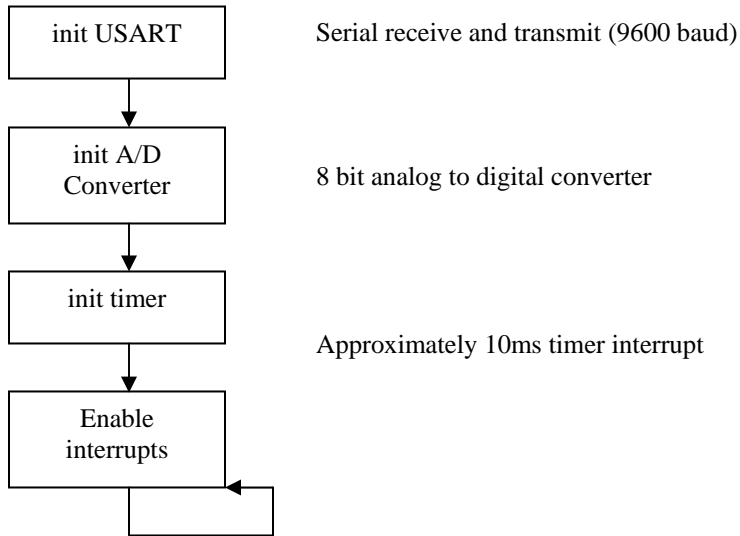
#### Serial received interrupt



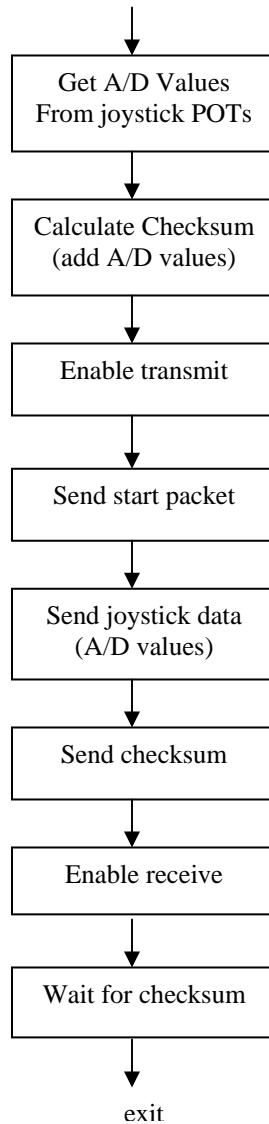
## Appendix 4

### Topside Control Flow Chart

#### Main



#### Timer Interrupt



<b>Density of Fluid (water) (kg/m<sup>3</sup>)</b>	<b>Gravity (m/s<sup>2</sup>)</b>
1000	9.81

<b>FRAME</b>	<b>PVC PIPE</b>
Length (m)	Density (kg/m <sup>3</sup> ) 1380
Height (m)	
Width (m)	
Volume (m <sup>3</sup> )	
Buoyant Force (N)	
Mass (kg)	
Weight (N)	
$\Sigma F$	

<b>THRUSTER X 4</b>
Volume (m <sup>3</sup> )
Buoyant Force (N)
Mass (kg)
Weight (N)
$\Sigma F$

<b>ELETRONIC BOX</b>
Length (m)
Height (m)
Width (m)
Volume (m <sup>3</sup> )
Buoyant Force (N)
Mass (kg)
Weight (N)
$\Sigma F$

<b>BATTERY BOX</b>
Length (m)
Height (m)
Width (m)
Volume (m <sup>3</sup> )
Buoyant Force (N)
Mass (kg)
Weight (N)
$\Sigma F$

<b>CAMERAS</b>
Volume (m <sup>3</sup> )
Buoyant Force (N)
Mass (kg)
Weight (N)
$\Sigma F$

<b>LIGHTS</b>
Volume (m <sup>3</sup> )
Buoyant Force (N)
Mass (kg)
Weight (N)
$\Sigma F$

<b>MISSION 1 MANIPULATOR</b>
Volume (m <sup>3</sup> )
Buoyant Force (N)
Mass (kg)
Weight (N)
$\Sigma F$

<b>MISSION 2 MANIPULATOR</b>	<b>ABS</b>
Volume (m <sup>3</sup> )	Density (kg/m <sup>3</sup> )
Buoyant Force (N)	
Mass (kg)	
Weight (N)	
$\Sigma F$	

<b>MISSION 3 MANIPULATOR</b>
Volume (m <sup>3</sup> )
Buoyant Force (N)
Mass (kg)
Weight (N)
$\Sigma F$

<b>Bouyancy Compensator</b>
Volume (m <sup>3</sup> )
Buoyant Force (N)
Mass (kg)
Weight (N)
$\Sigma F$

Total (mission 1) =  
 Total (mission 2&3) =

## Appendix 6

Proposed Actual

**Control System**

Video Cameras		\$600.00
Motor Drivers		\$134.00
Tether		Donated
Signal Converter		Donated
ATmega32		Donated
ATmega16		Donated
Miscellaneous		\$50.00
<b>Sub-total</b>	<b>\$600.00</b>	<b>\$784.00</b>

**Tools**

Messenger Line Threader		\$10.00
Robotic Hand		\$82.00
Suction Unit		\$30.00
Gasket Installer		\$20.00
<b>Sub-total</b>	<b>\$200.00</b>	<b>\$132.00</b>

**Chassis**

PVC Conduit		\$9.00
Couplings		\$25.00
PVC Cement		\$6.00
Mounting Brackets (1/2")		\$9.00
<b>Sub-total</b>	<b>\$50.00</b>	<b>\$49.00</b>

**Propulsion**

Rule Bilge Pump Motors		\$220.00
Propellers		\$75.00
Motor Clamps		\$10.00
Acrylic Sheet (1/2" and 5/16")		\$60.00
Shroud		\$9.00
Mounting Hardware		\$10.00
<b>Sub-total</b>	<b>\$400.00</b>	<b>\$384.00</b>

**Total Cost of the ROV**

\$2,708.00

**Travel / Competition**

Airfare		Donated
Accomodation		\$245.00
Transportation		\$700.00
Food		\$1,260.00
Poster and Team Equipment		\$100.00

**Total Expenses**

\$5,013.00