Heritage Collegiate Presents

Heritage Robotics

featuring ROV Thetis

Team

Dia-Lynn Ayles	Gavin Diamond
Julie Penney	Adam Pike
Brandon Howse	Michael Holloway
Devin Russell	Courtney Russell
Andrew Maillet	

Mentors: Mr. Michael Spurrell
Mr. Travis Oldford

Table of Contents

Abstract

Heritage Robotics is a team comprised of nine students and two mentors from Heritage Collegiate, Newfoundland, Canada. In February of 2007, the team dedicated themselves to the International ROV Competition organized by the Marine Advanced Technology Center.

The competition requires teams to design and build a remotely operated vehicle (ROV) that will be able to complete three specifically outlined missions. To solve these missions, the team was organized into several divisions (Appendix A) and followed a nine-step problem solving process (Appendix B). The design and configuration of the end effectors were among one of the team's main priorities. By following the design process, we were able to produce the most practical and successful products.

In the end, the ROV was a box type frame consisting of several removable payload tools. It also consisted of an easily controlled, yet versatile system for locomotion as well as a visual sensor. Through extensive testing and competition our ROV has proved to be well designed which has led us to great success.

ROV Thetis

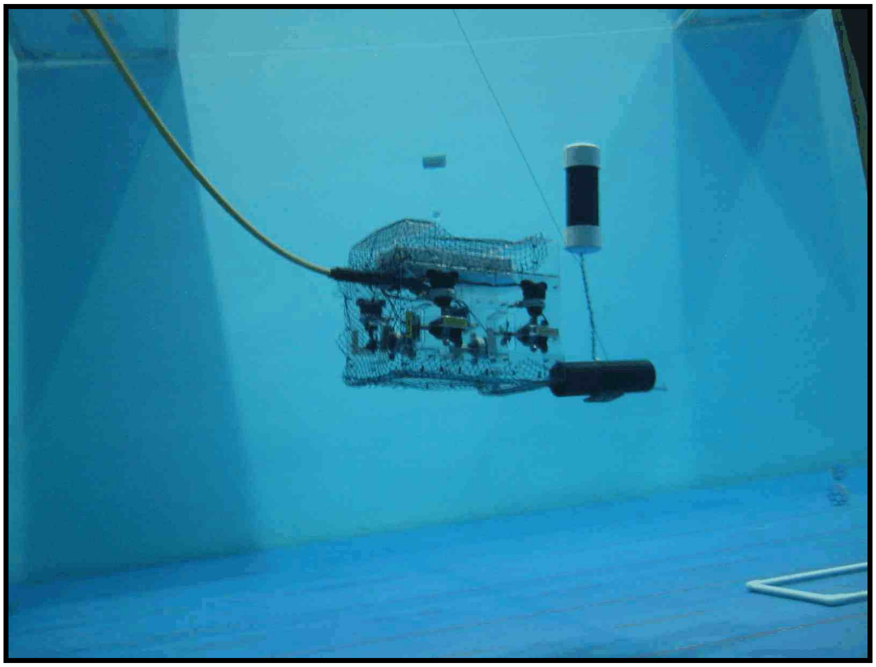
Introduction

At Heritage Collegiate nearly four months ago a group of nine students came together to discuss and research the ROV Competition. It was then decided that we were no longer students, but robotic engineers. Our first steps were not those of amateurs, but rather those of professionals. There were many concerns and ideas considered for the final ROV, and over a period of approximately four months of planning and engineering, we built our masterpiece.

The primary goal of this project was to build a remotely operated vehicle (ROV) which could complete a number of set tasks. Due to the number and diversity of these tasks, we had to carefully and diligently plan out the design of our ROV. This required the creation of a rigid frame, useful end effectors, and a versatile propulsion system. It also required some form of buoyancy, effective sensors, and proper wiring. Ultimately, it was a difficult engineering task, but the dedication of our team made it possible for us to succeed.

This project had many expenses such as acquisition of tools, materials, and travel. The scale of this project demanded many sacrifices from our team members. However, after long hours of effort combating technical problems and overcoming the challenges of working in a group, our team pulled through. Throughout the project, we became informed on a number of different facts, including the Polar Regions and how these regions impact - and are being impacted by - our global climate.

The Heritage Robotics team spent countless hours planning, building, and field testing. We are very proud of what we have accomplished and are honored to represent Newfoundland at the International Competition.



Thetis deploying the PAS

Mission Overview

Mission #1: The SmartBay Project in Placentia Bay

The mission is modeled after actual developments that occurred at the SmartBay Project in Placentia Bay, Newfoundland (figure 1.) Scientist have deployed a buoy (figure 2.) to monitor the marine ecosystem and improve weather forecasting for the Placentia Bay area. During a recent storm the buoy broke free of its mooring and a ROV was needed to reattach the chain.

The main objective of the ROV in mission one is to thread a messenger line through an anchor ring that is placed at the bottom of the flume tank. The anchor (figure 3) has a concrete circular base with a U-bolt projecting from its center.


Figure 1. Placentia Bay


Figure 2. Buoy #1


Figure 3. Anchor Ring - Prop

Mission # 2: NOAA's "Hidden Ocean" arctic expedition

During the summer of 2005, a team of scientists set out to explore and study the frigid depths of the Canada Basin (figure 4), a 3.7 kilometer deep bowl adjacent to the Beaufort Sea, which is located north of the Northwest Territories and west of Canada's Arctic islands. The scientific objectives were to study the Canada Basin from the surface of the ice to the bottom of the deep sea, cataloging the organisms (figure 5) found throughout that range.

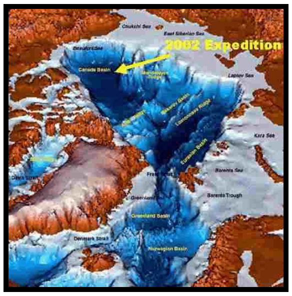


Figure 4. Canadian Basin


Figure 5. Benthic Jellyfish

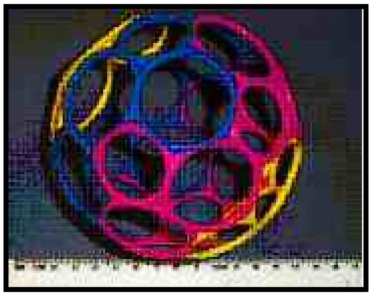


Figure 6. Benthic Jellyfish Prop

The ROV is required to do three tasks, task one is to collect one O-ball (figure 6) from the bottom of the ice tank which resembles a benthic jellyfish, and return it back to the surface. Task two is to collect a ping pong ball (figure 7) from under the ice sheet, which resembles a sample of algae. Task three is to transport and deploy a Passive Acoustic Sensor (PAS) (figure 8) and it's attached communication cable to a 0.5m by 0.5m designated area at the bottom of the ice tank.


Figure 7. Algae - prop


Figure 8. PAS - prop

Mission # 3: Hibernia platform

Discovered in 1979, the Hibernia oil field is located in 80 meters of water 315 km east/southeast of St. John's, Newfoundland, Canada. Currently the Hibernia platform (figure 9) has the capability of producing more than 200,000 barrels of crude oil per day, which it ships to refineries in Canada, the United States, and other countries depending on the demand. The platform could support additional production, if new reservoirs were discovered.

Our teams' mission is to simulate the preparation of a new wellhead (figure 10) which involves a series of tasks. A gasket (figure 11) must be transported to a wellhead. The ROV must remove the wellhead cover, insert a gasket, and then replace the cover. Finally a hotstab (figure 12) must be inserted into the well head and returned to the surface.


Figure 9. Hibernia Platform


Figure 10. Well Head


Figure 11. Gasket


Figure 12. Hotstab

Design Rationale

The ROV required a design that would allow it to travel and maneuver easily, while still being able to perform the mission tasks. There were six main components of the design that had to be planned in great detail: frame design, motor placement, end effector design and placement, buoyancy, sensors, and the electronics. Each separate component needed to mesh well with the other five components to produce a functional design.

Frame

The first component considered was the frame design. A specific type of body was needed to satisfy several requirements. The frame (figure13) had to be rigid, stable, allow attachment of end effectors, and have little drag. After a series of numerous designs the group decided on an open-ended box shape design which satisfied each of the requirements and also allowed easy access to the ROV's internal components. Seven millimeter Lexan was chosen as the building material since it is strong and rigid, yet can be easily bent and molded with the application of heat.

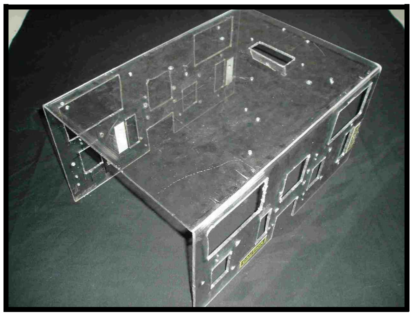


Figure 13. The ROV Frame

Propulsion

The motors (figure 14) are taken from 5000L/h Johnson bilge pumps. The group simply had to remove the bilge pump housing (figure 15), attach propellers to the ends of the prop shafts, and then attach these prop shafts to the motors. These motors also exert a force of approximately 7 N each and draws 1.3 A of current out of water and 2.8 A in water. We used a bollard test to determine this information (Appendix C). To mount these motors onto the ROV each motor was first placed inside a short piece of 3cm inch PVC pipe. This pipe was then glued to a plastic bracket and the set screw was tightened to ensure that the motor would not shift. The motors were then attached to the ROV by placing a bolt through each of the two holes on the bracket and attaching these bolts to the frame.


Figure 14. Bilge Pump Motor


Figure 15 Bilge Pump Housing


Figure 16. Propeller and Shaft

The group decided to use four vertical motors to create sufficient lifting force and speed. These were positioned in such a way so that there are two motors on either side of the ROV. This causes the ROV's center of gravity to be at the structural center. Furthermore, four horizontal motors were used since it allows the ROV to move swiftly in water and with increased maneuverability. These were positioned at each of the ROV's inside corners to provide balance and stability.

The propellers (figure 16) on the ROV consist of four plastic blades and are 70 mm in overall diameter. The distance across the circle which the propeller tips make while rotating is 70 mm. It also has a pitch of 35 mm, which means, it moves forward 35 mm for every one full rotation of the propeller. The rake (the degree that the blades slant forward or backward in relation to the hub) is 20 degrees. It also has a 5 mm female brass insert head.

These propellers were chosen based on several factors including; diameter, pitch, weight, price, and availability. To test how these would affect the overall mission performance, a series of investigations and a bollard test (Appendix C) were performed. Also, the diameter of the blade must exceed that of the motor in order to produce sufficient thrust. The pitch of the blade, which depends on the diameter and the rotational speed of the motor, was also an issue. The propellers which were selected have a pitch of 35 mm, which provide considerable thrust without drawing too much current. The propellers are lightweight and thin, which are the optimum type for higher speed applications and enable our ROV to complete its mission tasks more quickly and efficiently. Price and availability were also an important concern. Our propellers were inexpensive and simple to locate.

To attach the propellers to the bilge pump motors, a shaft (Figure 16) was machined from brass rod. The shafts consist of a 5 mm male brass head and attaches securely to the motor using a brass set screw. Brass was used to avoid both rust and corrosion of the shaft.

End Effectors

The most critical part of our ROV was the end effectors. Without these tools, the ROV would be unable to perform any actions other than motion. It was very important that these tools were effective, but also simple in design and function. A simpler tool that works as well as a complicated tool is less likely to break, and is easy to repair or replace.

A variety of specific end effectors were used to complete each tasks. These will be discussed in more detail later. However one end effector was common to each mission; the Electronic Release Mechanism (figure 17). It was constructed from an electronic trunk release salvaged from a regular

Figure 17. Release Mechanism

automobile. Modifications were made to the casing, the hook was redesigned to attach to a U-bolts, and a ground wire was added to complete the circuit. The system consists of three components; a solenoid, a metal latch, and a metal pin. While the mechanism is closed, the pin pushes against the latch, holding it in place. When an electric current passes through the solenoid, a magnetic field is produced, pulling the pin backward and releasing the latch. The tool was placed in the middle of the ROV which allows for balance and easy access. The end effector is triggered by an instantaneous switch on the control box.

Buoyancy

The final step to completing the ROV is tuning the floatation system for each mission. The goal was to construct an ROV which would be stable and neutrally buoyant under water. This was accomplished through repeated testing and evaluation. Buoyancy was attained by using foam (figure 18), held in place by lexan brackets. The foam was cut into a large rectangular shape, pointed at the front to reduce water resistance. A high-density foam was chosen since lower density foam can compress under water and thus cause the ROV to lose buoyancy. The amount of foam was determined by trial and error and was chosen to be the proper amount to cause the ROV to be neutrally buoyant.

Figure 18. High-density Foam

Sensors

The only sensor placed on the ROV is the underwater camera used for navigation. Thetis' camera (figure 19) is model LCA7700C supplied by Lights Camera Action. It has a highly sensitive color module that requires only 0.0001 Lux (the amount of visible light per square inch meter incident on a surface). It is equipped with 6 built in infra-red LEDS and IR-sensitive color reproduction. The LCA7700C has a horizontal resolution of 380 TV lines, an imager with 1.8cm color CCD, a picture element of 290,000 pixels, and a video output of 1V p-p obm composites. To operate, the LCA7700C requires a power source of DC 12V with a tolerance of 9-15V. It uses a 3.6 mm (92 degree) lens and has a depth of 33 meters. We used this camera because of some of its helpful features, such as a wide angle, its light weight and a completely waterproof design. It also exhibits a live and vivid picture quality with built-in video enhancing technology and has been specifically designed for ROV use.

Figure 19. LCA7700C

After choosing the camera, the next task was to determine where to mount it on the ROV. It was positioned near the back of the ROV and is angled slightly downwards to provide the driver with a maximum viewing area, as well as a better view of the end effector and the area slightly below the ROV.

Electronics

An important aspect to any ROV is its electronic systems. An ROV requires electronics to operate its motors, receive input from sensors, and send control signals to the ROV. It was critical that our electrical system to be well arranged as well as safe to be used in water.

- Controller

The electronic navigation controller (figure 22) is housed in transparent lexan and fitted with several switches. The system was preferred over variable controls since it is very reliable and low maintenance. The size of the controller was chosen to fit the pilot's hands, allowing for multiple switches to be controlled with ease. It features three two-way momentary switches to control the horizontal and vertical thrusters and a single momentary switch which operates the release mechanism and the algae collector in mission two. The design was tested and found to allow the precision control necessary in the movement of the ROV.

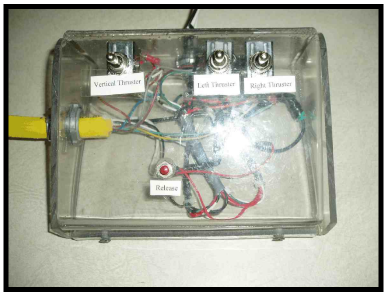


Figure 20. Navigation/Electronic Controller

- Tether

The tether (Appendix D) used on the ROV measures 11.27 m long, cost $106.38, and is neutrally buoyant. It contains nine wires, one of which is a coaxial cable used for the camera while the other eight are used for the end effectors and powering motors. A filler in the tether makes it neutrally buoyant as it eliminates air and causes the tether to be of the same density as water. The tether also has a protective polyurethane coating that protects the tether managers from electric shock.

- Fuse

A primary safety feature in the ROV's electrical system is the inline fuse (figure 21). A fuse is a small safety device in an electrical circuit which causes it to stop working if the electric current becomes too high, thus preventing fire or other dangers. The fuse is placed between the control box and positive terminal on the battery. If a power surge or short circuit occurs, the thin metal filament in the fuse will burn out, stopping all electrical current. This will prevent the wires and electronic systems on the ROV from overheating and damaging themselves. The fuse can carry a maximum of 25 amperes prior to breaking the circuit.

Figure 21. 20 Amp Fuse

The Missions: How we did it!

Mission #1: The SmartBay Project in Placentia Bay

To complete the task quickly the team designed an end effector that could thread the messenger line through the anchor ring in a single motion. The end effector consist of two parts: a feeder base (aluminum rod) and a pivoting locking arm constructed of lexan. The messenger line is attached to the anterior end of the feeder base which is attached to the ROV by the release mechanism. The pilot steers the posterior end of the feeder base and the carabineer through the anchor ring. Once this happens the ring strikes the trigger which in turn releases the locking arm. The locking arm rotates clockwise, hooking itself onto the carabineer. This single motion attaches the feeder base to the ROV at two separate positions on either side of the anchor ring. From the surface the pilot then signals the release mechanism to disconnect, allowing the feeder base to be pulled cleanly through the anchor ring with the messenger line attached.

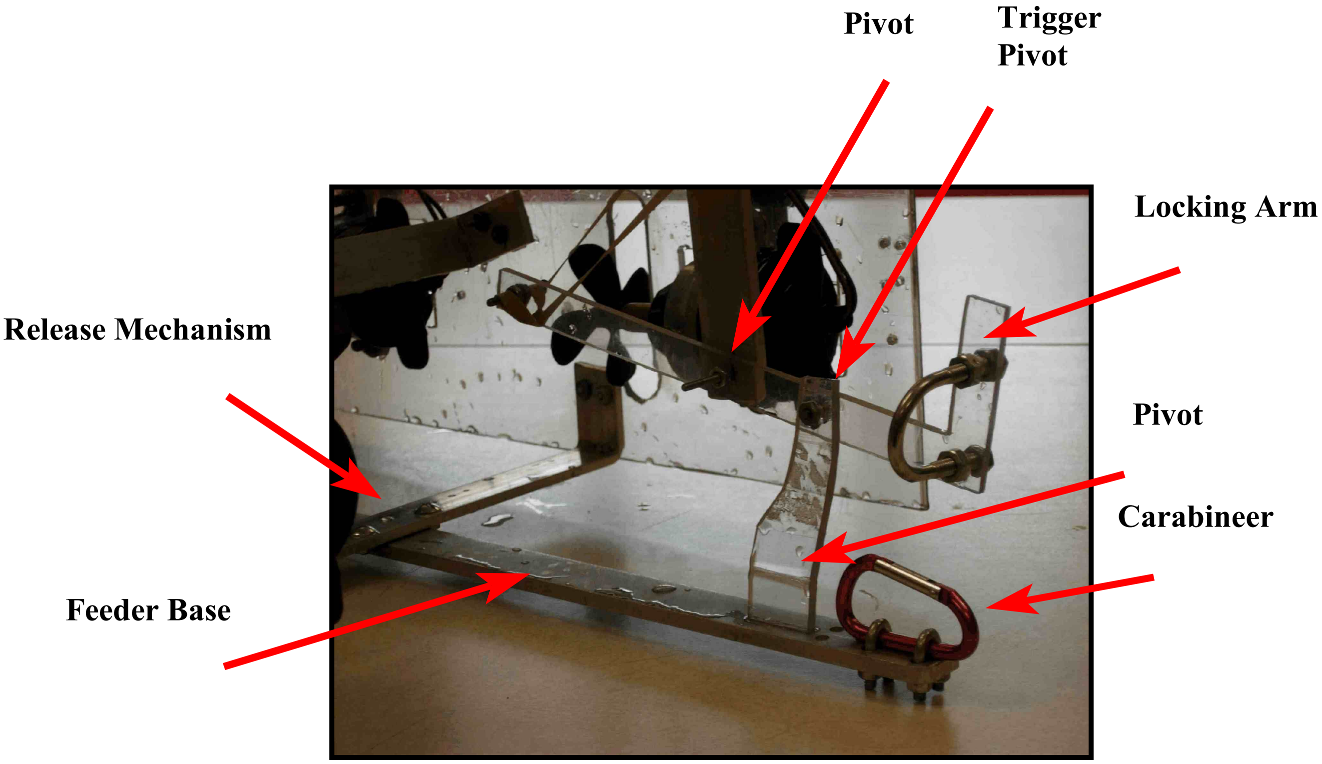


Figure 22. Mission 1 End Effector

Mission # 2: NOAA's "Hidden Ocean" arctic expedition

Three separate end effectors were designed to complete this mission which took advantage of the ROV's box-shaped frame. A net was wrapped around the frame to create a scoop which was used to pick up the benthic jellyfish. The PAS may be transported to the ocean floor by inserting an aluminum rod through its hollow core, similar to a forklift moving a pipe on land. The final task, retrieving the algae, is a little more complicated. Initially it was decide to mount a net on the top of the ROV. However, this proved to be insufficient, so the team designed a vacuum using a bilge pump and hose to suck up the algae.

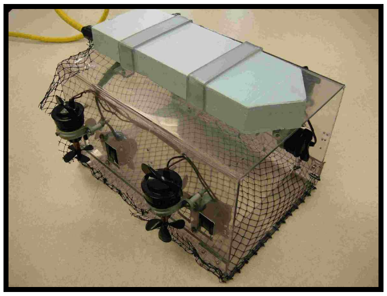


Figure 23. Row with Net

Figure 23 Bilge Pump Housing

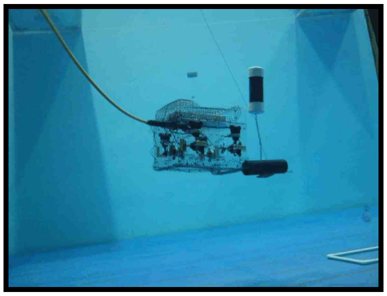


Figure 24. Deploying the PAS

Mission # 3: Hibernia platform

The final mission also required the use of several end effectors. A simple straight aluminum rod bent at a 30 degree angle was used to carry the gasket and remove the cover from the well head. To insert and release the hotstab, the feeder base from mission one was modified (figure 25). The front end where the carabineer s located is attached to the hotstab and the rim of a plastic bucket was attached to the anterior end. Once the hot stab is inserted into the wellhead, the feeder base is released from the ROV (figure 26). Then a hook (figure 27) on the front of the ROV is used to capture the feeder base and attached the hotstab and return it to the surface.

Figure 25. feeder base and hotstab

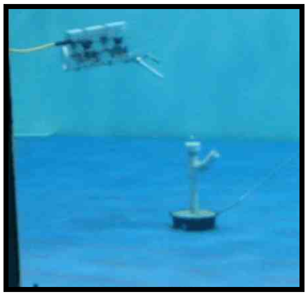


Figure 26. Mission 3

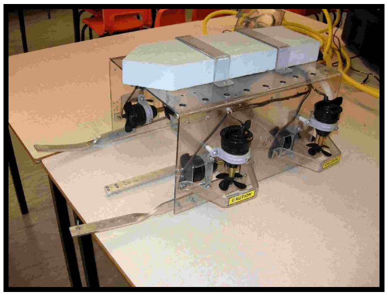


Figure 27. Hook on ROV

Budget

One major factor that had to be considered was the budget (Appendix E). As this was the second year involved in the competition, many of the materials and tools needed were already purchased. Nonetheless, there were some additional materials required. The team had to depend on student resources, fund-raising, and donations. Every student paid a small fee and held a variety of fund-raisers, which included everything from selling tickets to pizza sales. Various organizations donated money and resources to our cause, including a large test tank which was built and donated to our school. Since our school is located in the rural community of Lethbridge, there were also the expenses of traveling to the swimming pool for practice and to the regional competition. Overall, our total expense was $1545.56 and income was $2500.00.

Trouble Shooting

The Technique

When working with and testing the ROV, the team is always aware of existing and potential problems. When a problem occurs with the ROV's performance the team follows a nine-step problem solving process (Appendix B). The team first tries to identify what exactly is the problem and develops a design brief to identify the specifications and limitations. Once the problem and its source are identified, the team conducts research (figure 28) and brain-storms (figure 29) to come up with possible solutions. From the proposed solutions the team would determine the advantages and disadvantages of each and decide which is the optimal solution. A prototype (figure 30) is constructed and repeatedly tested and evaluated. In the end if the solution is not adequate the process is repeated for redesign and improvement.

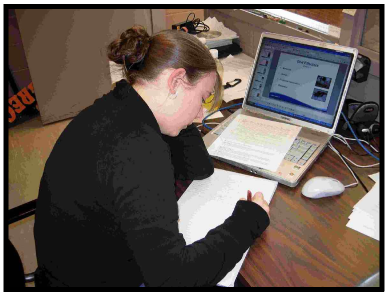


Figure 28. Courtney Researching

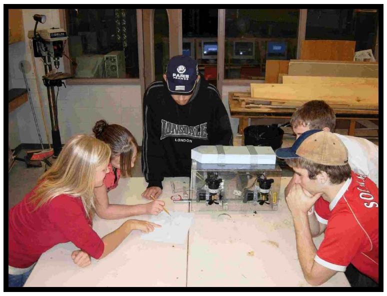


Figure 29. Brainstorming

Figure 30. Testing prototypes

Sample Problems/Solutions

When constructing the underwater ROV, the team encountered a number of problems which could have created severe disadvantages. One of the problems that we encountered involved the carabineer not snapping shut. The reason for this problem was that its back was curved. When we tried to tighten the carabineer to the aluminum rod it bent apart and this caused it not to shut properly. As a solution we shaved the back of the carabineer flat so that it didn't bend when we tightened it. As a result the carabineer could shut and function properly.

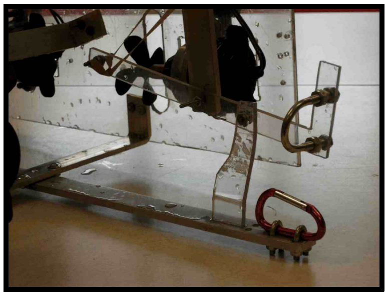


Figure 30. Carabineer

A second encountered with our ROV was that it wasn't able to pick up the ping pong ball properly during the regional competition. This cost our team some points and we were not able to complete mission two. During the regional competition, our plan was to scoop up the ping pong ball with a large mesh net on top of the ROV. As a solution, our team chose to make a vacuum out of a bilge pump that could collect the ping pong balls using suction.


Figure 31. Bilge Pump

Another problem encountered with our ROV was again during the second mission but this time it involved the benthic jellyfish. During practice when the ball was scooped up by the ROV, it would strike the propellers (figure 32). This would cause the propeller to come unscrewed from the shaft of the motor. As a solution for this problem our team designed guards out of lexan to protect the propellers, and to stop the ball from hitting them as it entered the ROV.

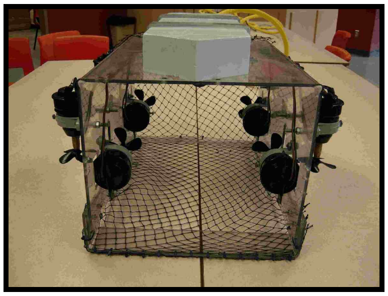


Figure 32. Unprotected Propellers

The final problem encountered with the ROV involved the third mission. We had extended two rods (figure 33) from the robot to hold the wellhead and gasket. After practice we determined that the arrangement was fine when the ROV moved forward but the objects would slip off when moving in reverse. The team re-evaluated the situation and determined to bend the rods at a precise angle; enough to hold the objects in reverse and still allow them to slide of when needed..

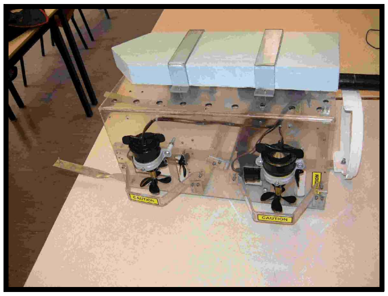


Figure 33. Extensions

Future Improvements

As pleased as anyone can be with their final product, there will always be room for improvements and variations. Our ROV is no exception, regardless of how impressive its performance can be. Observing flaws and creating ideas to fix them are easier said than done, especially in a short time frame. If time could be turned back however, there are a number of things we would have done differently. One mistake on our part was underestimating the time we needed to allot for planning and preparations. Knowing the data we now have on our ROV's performance and the various modifications needed to make it into an effective machine, we realize that the time spent doing these modifications could have been cut in half. More time would be put into research on neutral buoyancy and other factors such as motor thrust and our ROV's lifting capacity. As the old saying goes "Practice make perfect," and that is one thing we did not do enough of. The pilot of our ROV has only had adequate practice time completing the missions and maneuvering the ROV, where as they should have had a major amount of time practicing. If we could repeat the project, we would definitely put more time into planning and practice.

Challenge

During the construction of the ROV (figure 34) the team experienced many miniature problems that meshed together and resulted in the creation of a single major challenge. As days passed, individual problems caused a substantial amount of time to be lost and resulted in the primary problem; a lack of time. The team was determined to have the ROV ready many days in advance, which would demand an immense amount of dedication. Not only did the ROV have to be constructed, but other parts of the project such as the presentation and poster board had to be completed. It was soon decided that much more time must be dedicated to the project. Along with the time spent during lunch hours it was agreed that time after school would be required to complete the ROV (Appendix F). Work intensified, and a number of students remained after school to work for many additional hours. The team managed to complete the construction a few days in advance, allowing the pilot to have sufficient practice time.

Figure 34. The team during the construction process

Life at The Poles

The Poles

Both the Arctic and Antarctic seem beyond life: icy, treeless, hostile places. Yet these polar regions (figure 35) host a surprising abundance of life, ranging from the microbial to the awe-inspiring, from bacteria to bowhead whales.

However, there are important differences between the North and South Poles. The North Pole lies in the middle of the Ocean surrounded by land, while the South Pole rises from the center of a continent surrounded by an ocean. The North Pole has supported Inuit and other indigenous peoples lives who have used aged-old traditions while now using modern technology to help with everyday tasks. The South Pole has no native human populations other than visiting scientists and supporting personnel from year to year. In the North Pole scientists focus on human migration and their methods of interacting with the environment. However, at the South Pole scientists have focused on the effects of isolated and confined environments.

The Poles are poorly understood places. Because of this, scientists have organized special efforts called the International Polar Year (IPY). During the first Polar Year (1882-1883) data was collected on weather patterns, the earth's magnetic force, and other polar phenomena that affected navigation and shipping from the second Polar Year (1932-1933) contributed to new meteorological maps for the Northern hemisphere and verified the effects of magnetic storms on radio waves. Beginning this year, from March 2007 to March 2009 scientist will host the fifth IPY and will involve over 200 projects, with thousands of scientists from over 60 nations examining a wide range of physical, biological and social research topics (IPY. 2007)

Figure 35. North Pole

INTERNATIONAL 2007 2008
POLAR YEAR

The Inuit Way of Life

The Inuit ancestors likely crossed over the land bridge from Asia around 3000 BC to an Arctic North of endless landscape of tundra and ice (Bennett, 1997). The Inuit name for themselves translates in English to "the people". They have well adapted to this treeless landscape where the ground stays mostly frozen all year round and the temperature rarely rises above 50 degrees Fahrenheit in the summer.

Peoples (figure 36) such as the Inuit living at the North Pole have adapted themselves to harsh conditions. Between March and November there is darkness 24 hours a day. Yet between May and September the sun never goes down. They experience severe winter storms and temperatures and unpredictable food sources. The Inuit use what nature provides for them: meat from fish, seal, walrus and other game. Utilizing thread from caribou sinew, and needles made from bone, they make their own clothes from wild game. Fur coats are made from bearskin, seal, caribou, or fox fur. Waterproof parkas are made from the intestines of seal or walrus while boots are made from sealskin, and hoods are lined with fox tails. Dome-shaped igloos are often built in winter to provide shelter from bad weather. Fur blankets provided warmth while oil from whale or walrus provided fuel for their lamps. In the summer, conical tents are used. The Inuit travel over land by dogsleds called komatik and through water by using kayaks and umiaks. Indeed, the Inuits are a very resourceful people.

Figure 36. Inuit

Figure 27. Inside an Igloo

Reflections: Most Rewarding Experience

This project was a huge undertaking for all of the team members involved. Relentless hours of work and tireless effort have contributed into making this project a great success. Just completing this task was an amazing experience, and one that we are all proud of. Yet, there was something more, a certain feeling created by taking on the building of a ROV, that was the most rewarding of all. We got to live, work, and feel like real engineers. The planning, the perfecting, the determination, the pressure, and it all had to be completed within a restricted time frame. Each member working diligently on their assigned duty, but always in communication with everyone else to ensure everything was going smooth. It gave us the feeling of a real life scenario: we had to get this done, and we had to get it right. The way we pulled together as a team ensured the workload was spread out evenly, and we constructed our ROV with utmost care and consideration. The feeling of teamwork is definitely the most rewarding experience we could have asked for.

Acknowledgments

Heritage Robotics would like to thank our team mentors, Mr. Michael Spurrell and Mr. Travis Oldford. It was the knowledge and advice of our mentors that helped us to design our ROV and their constant support and encouragement that kept us going. We would like to thank our parents for their tremendous support through finances and transportation. Also, thank-you to our school teachers who dedicated their time and assistance.

In addition to the support given by our school and parents, there have been many companies and organizations (listed below) which have provided us with assistance and financial support.

MI MARINE INSTITUTE

North Atlantic
Refining and marketing quality petroleum products right here at home.

J-1 CONTRACTING LTD.

GEO CENTURY

Government of Newfoundland & Labrador

References

Bennett, Carol (1997) The Inuit. Retrieved May 22 from http://www.heritage.nf.ca/aboriginal/inuit.html

Button, Clar. (2004) *Building Your ROV A Manual for High School.* Avalon Robotics

Eastern Edge Robotics (2006) Principles and pedagogy. Retrieved May 22, 2003 from http://www.nsac.ns.ca/cde/staff/lcj/development/prototype/glossary.htm#kirkpatrick

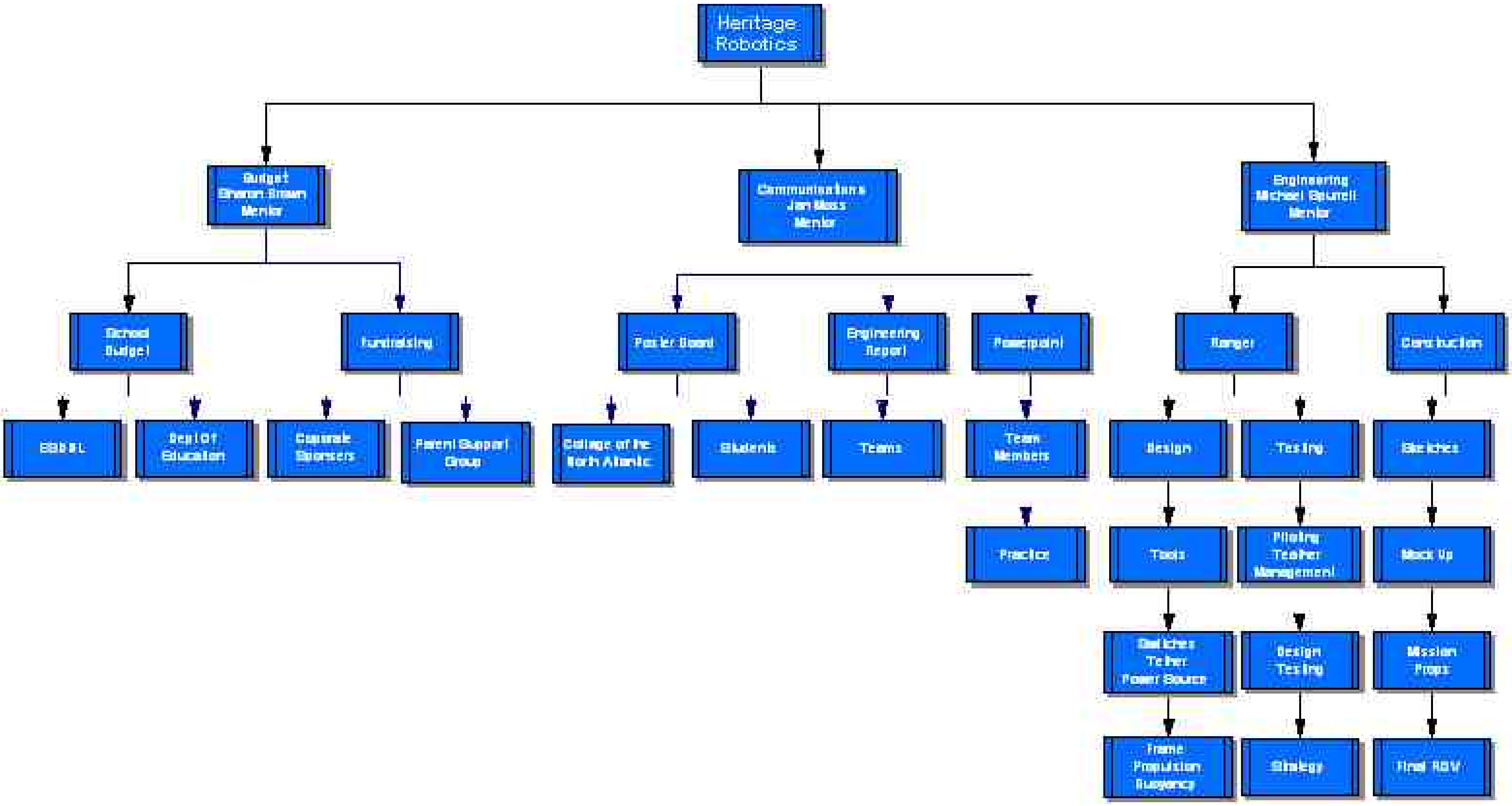
International Polar Year Homepage 2007, Retrieved May 9, 2007 from http://www.ipy.org/index.php?/ipy/audience/C31/

MATE. (2006) ROV Competition Page 2006, Retrieved March 10, 2007 from http://www.marinetech.org/rov_competition/2006/index.php

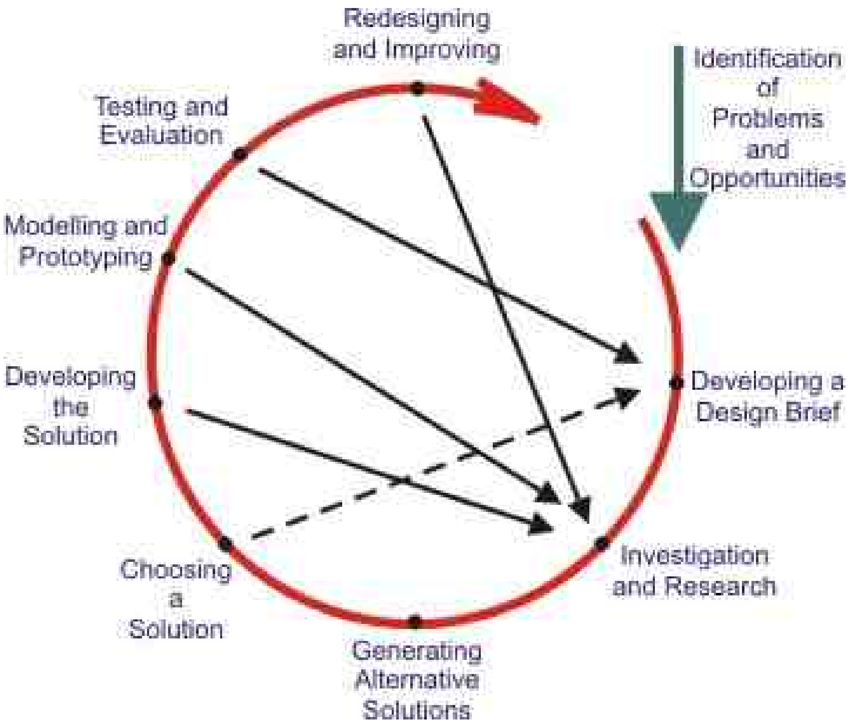
Smart Draw. (2006) Download Link, Retrieved May 12, 2006 from http://www.smartdraw.com/downloads/index.htm

Appendix A: Team Division

To solve the mission, the team was organized into several divisions as indicated.



Appendix B: Nine-step Problem Solving Process



Appendix C: Bollard Test

Table 1. Motor Force

	A (m)	B (m)	Forward Force First Trial (N)	Forward Force Second Trial (N)	Backward Force First Trial (N)	Backward Force Second Trial (N)
Test 1	1	1	7	8	2.5	2
Test 2	0.9	1.1	8	8.5	2.5	2.5
Test 3	0.8	1.2	8.5	9	3.5	3.5
Test 4	0.7	1.3	12.5	12.5	4.5	4

Average Forward Thrust = 6.7 N Average Reverse Thrust = 2.4 N

Table 2. Current Through Motor

	Forward Out of Water (A)	Reverse Out of Water (A)	Forward In Water (A)	Reverse In Water (A)
Test 1	1.4	1.5	2.9	2.5
Test 2	1.25	1.3	2.8	2.4
Test 3	1.4	1.3	5.8	2.2
Test 4	1.3	1.4	2.7	2.5

Average Submerged Forward Current = 2.8 A
Average Forward Current (Not Submerged) = 1.3 A

Average Submerged Reverse Current = 2.4 A
Average Rev. Current (Not Submerged) = 1.4 A

Sample Calculation:

F: force applied by motor
M: force applied by force meter
T: torque)

T=M•A and also **T = F•B**

Therefore,

$M \cdot A = F \cdot B$
$(8.5N)(0.9m)=F \cdot (1.1m)$
$(8.5N)(0.9m)/(1.1m)= F$
$F = 6.95\ N$

Appendix C: Bollard Test

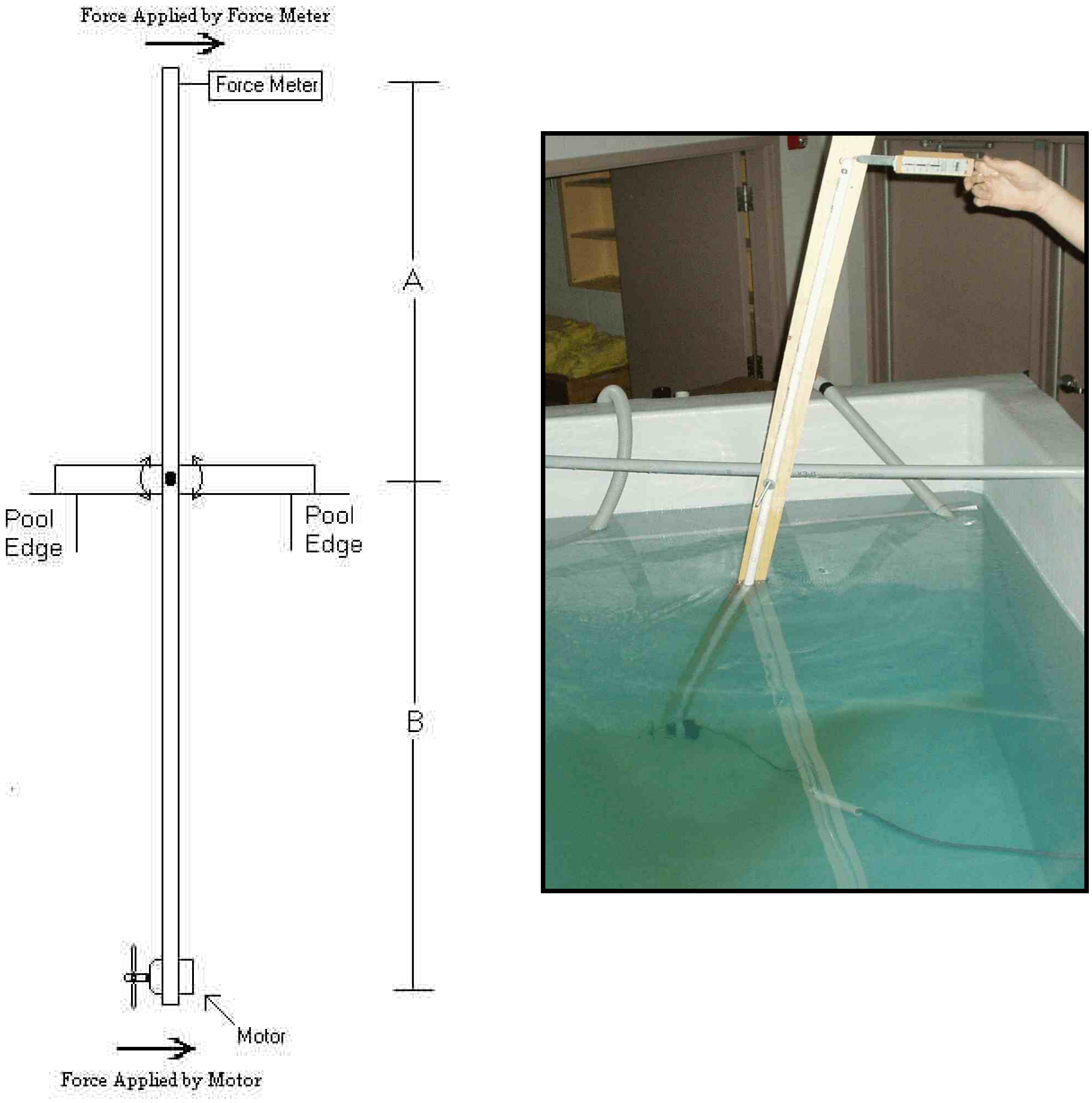


Figure 1: Bollard Test Apparatus

Appendix D: Electric Schematic

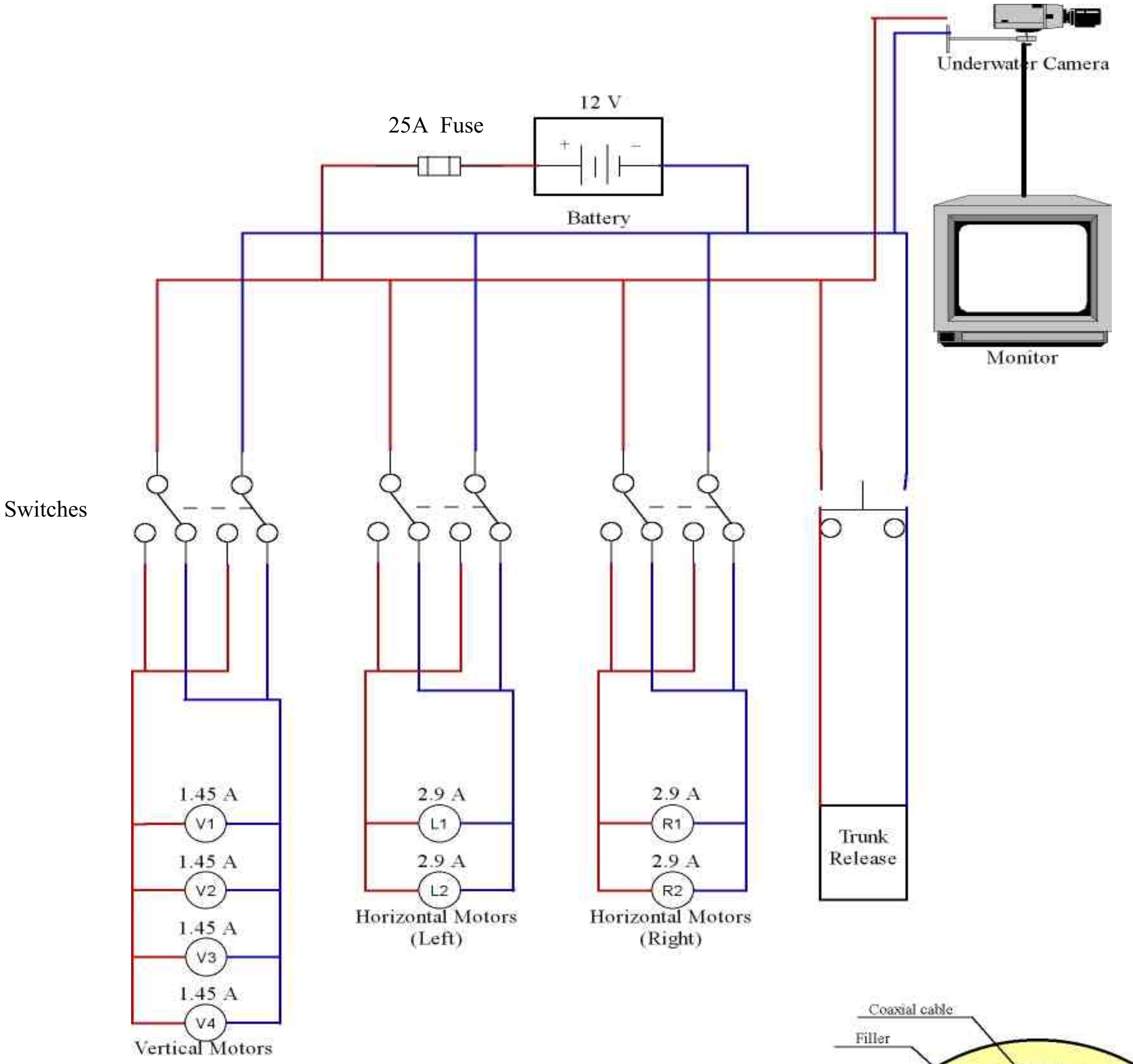


Figure 1. Schematic

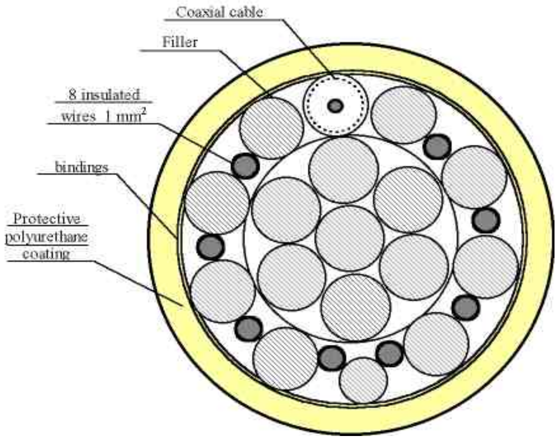


Figure 2. Tether cross-section view

Appendix E: Budget

Budget/Expense Sheet

Team Name: Heritage Robotics

Mentor: Michael Spurrell

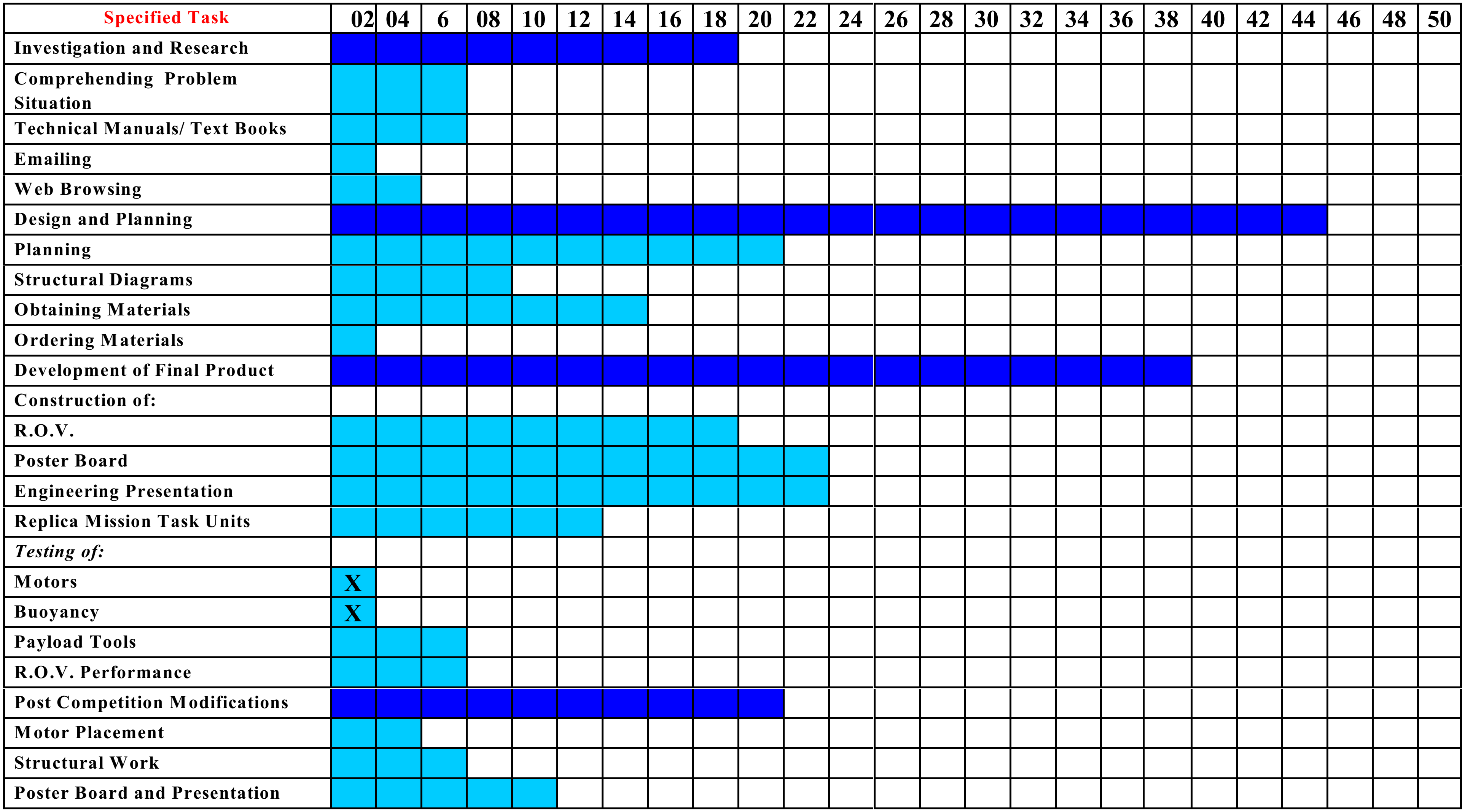
Description	Unit Price	Quantity	Cost	Balance
Bolts	$0.50	26	$13.00	$13.00
Electrical Tape	$0.62	1	$0.62	$13.62
Epoxy	$11.69	1	$11.69	$25.24
Glue	$0.10	1	$0.10	$25.34
Nails	$0.04	100	$4.00	$29.34
Nuts	$0.05	32	$1.80	$31.14
1/4inch Screws	$0.05	16	$0.80	$31.94
1/8 inch Screws	$0.04	11	$0.44	$32.38
Zip Ties	$0.04	6	$0.24	$32.62
Batteries	Salvaged	1	-	$32.62
Cameras	$210.00	2	$420.00	$452.62
20 AMP Fuse	$7.00	1	$7.00	$459.62
Lexan	$200.00	1	$200.00	$659.62
Lock Tight	$7.50	1	$7.50	$667.12
Motors	$17.00	8	$136.00	$803.12
Propellers	$11.00	8	$88.00	$891.12
PVC Pipe	Salvaged	1	-	$891.12
Styrofoam	$195.00	1	$195.00	$1086.12
Switches	$12.99	4	$51.96	$1138.08
Tether	$106.38	1	$106.38	$1244.46
Trunk Release	Salvaged	1	-	$1244.46
Aluminum Rod	$24.32	1		$1268.78
Stock Paper	$15.78	1		$1284.56
Carabineer	$1.00	2		$1286.56
Wood	Salvaged	1	-	$1286.56
Strip Heater	$259.00	1	$259.00	$1545.56

Income

Description	Amount	Balance
Fund-raised	$350.00	$350.00
J-1 Contracting	$100.00	$450.00
GEO Century	$1000.00	1450.00
Marine Institute	$300.00	$1750.00
NL Governement	$200.00	$1950.00
Humby Motors	$50.00	$2000.00
North Atlantic Refining	$500.00	$2500.00

Balance: $954.44

Appendix Working Hours Time Chart



Specified Task	02	04	6	08	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
Investigation and Research	■	■	■	■	■	■	■	■	■																
Comprehending Problem Situation	▨	▨	▨																						
Technical Manuals/ Text Books	▨	▨	▨																						
Emailing	▨																								
Web Browsing	▨	▨																							
Design and Planning	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Planning	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨															
Structural Diagrams	▨	▨	▨	▨																					
Obtaining Materials	▨	▨	▨	▨	▨	▨	▨																		
Ordering Materials	▨																								
Development of Final Product	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Construction of:																									
R.O.V.	▨	▨	▨	▨	▨	▨	▨	▨	▨																
Poster Board	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨														
Engineering Presentation	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨														
Replica Mission Task Units	▨	▨	▨	▨	▨	▨																			
Testing of:																									
Motors	X																								
Buoyancy	X																								
Payload Tools	▨	▨	▨																						
R.O.V. Performance	▨	▨	▨																						
Post Competition Modifications	■	■	■	■	■	■	■	■	■	■															
Motor Placement	▨	▨																							
Structural Work	▨	▨	▨																						
Poster Board and Presentation	▨	▨	▨	▨	▨																				

(X = Less Than 2 Hours) **← Approximate Time in Hours →**