Heritage Collegiate Presents

Heritage Robotics

featuring ROV Poseidon

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Abstract

At Heritage Collegiate nearly three months ago a group of twenty-one students enrolled in the Robotics 3221 course. It was then that we decided that we were no longer students, but robotic engineers. The first steps in the course 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 two months of planning and preparations, 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 of the number and diversity of these tasks, our ROV had to be very well designed. 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.

This project had many expenses, such as the acquisition of tools and materials. Furthermore, we had to be ready to combat technical problems and overcome the challenges of working in a group. Finally, throughout the project, we became informed on a number of different facts, including knowledge in the different careers and businesses which make use of marine robotics technology.

The Heritage Robotics team spent numerous hours planning, building, and testing Poseidon. We are very proud of what we have accomplished and wish to do well in Texas.

Introduction

Heritage Robotics is a team comprised of twenty-one students and one teacher mentor from Heritage Collegiate, Newfoundland, Canada. In January of 2006, the team decided to compete at the upcoming 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 complete four interconnected tasks. First, teams are required to carry an electronics module and place it into a trawl-resistant frame. Afterward, the ROV must open the frame door, pick up the power-communications cable connector, and plug it into a small opening in the module (Figure 1). Finally, the ROV must pull a release pin from the elevated acoustic transponder.

To solve the mission, the team was organized into several divisions (Appendix A) and followed a nine-step problem solving process (Appendix B). In the end, the ROV was comprised of a boxtop frame consisting of four different payload tools, an end effector which can carry the module, an effector to hook and open the frame door, an effector to lift, plug in, and release the cable connector, and an end effector to hook onto and pull the release pin. It also consisted of an easily controlled, yet versatile system for locomotion as well as a visual sensor.

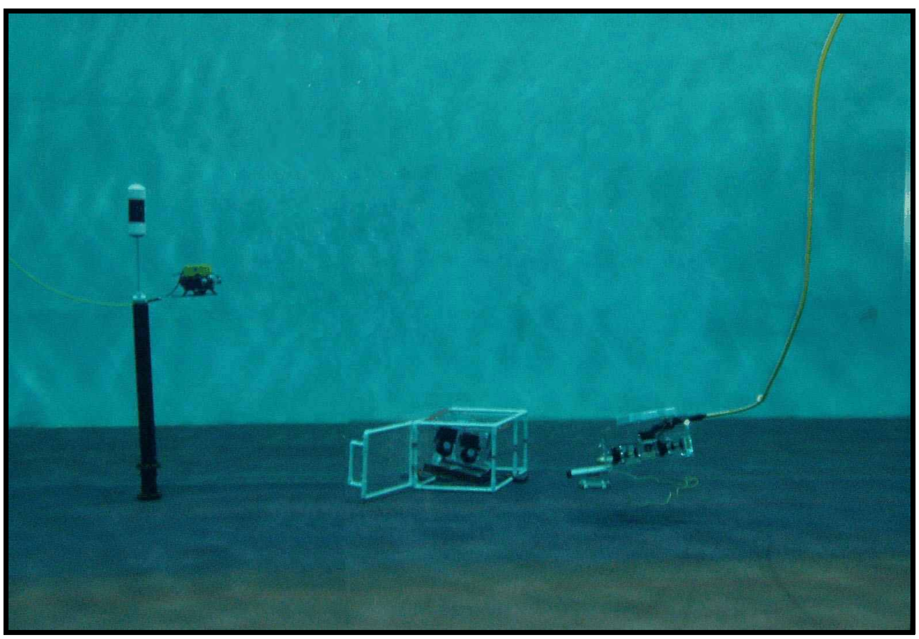

Figure 1. Poseidon completing the central node

Mission Overview

Mission Task 1

The first objective of the ROV is to transport an electronics module (Figure 2) from the surface to a trawl-resistant frame. The module must be placed into the top of the frame and the power/communications cable must be inserted into one of the two open ports located at the front of the electronics module.

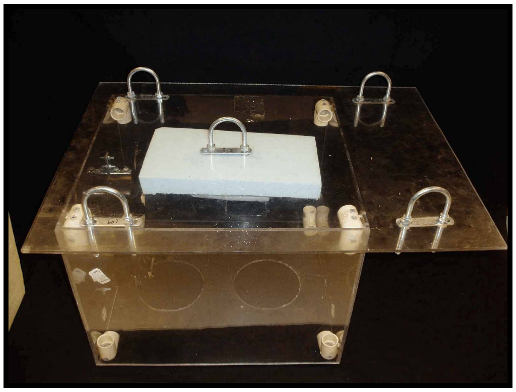

Figure 2. Electronics Module

The electronics module will be composed of plexiglass. The top surface is slightly larger than the base and measures 60 cm long and 44 cm wide. The module itself, suspended from the top horizontal surface, will be 40 cm long, 35 cm wide, and 30 cm tall. The two ports mentioned earlier, will be located about half way from the bottom of the module. One will be labeled, "Instrument Cable" and the other will be labeled, "Power Cable" (Figure 3). This module will weigh no more than 0.5 kg in water. On the top surface of the module, there will be a U-bolt in each corner, as well as one U-bolt which will be located at the center. These bolts are to assist in deployment and maneuvering. The U-bolts will be protruding from the surface more than 2 inches.

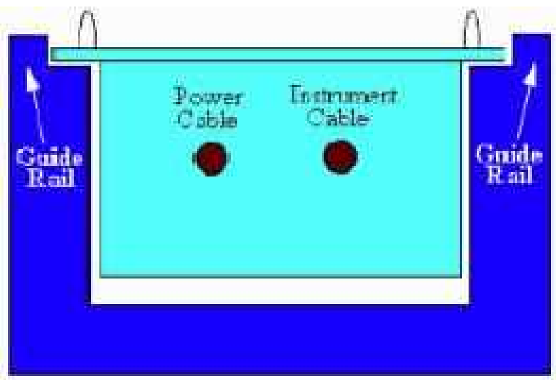

Figure 3. Electronics Module Labels

The trawl-resistant frame will be 75 cm long, 50 cm wide, 40 cm tall, and composed of PVC pipe. The opening of the frame however, will be 57 cm long and 40 cm wide. This will allow the body of the module to hang inside the frame, suspending from the top surface. There will be a guide rail attached to the frame. This will allow the top horizontal surface to just fit in, assuring the positioning of the module. When the module is placed in the frame, the two ports will be in front of the door to the frame, and when the door is opened, the submarine connector will have access to the correct port. The door of the frame will be composed of mesh with a solid frame of PVC pipe. This door will be attached to the frame by hinges that require less than one newton of force to open. The handle of the door will be 5 cm from the door on the right side and it will be 20 cm long internally. Once the door is opened, the power/communications cable connector (Figure 4) will be inserted into the port labeled “Power Cable.” This opening will have a depth and diameter of 7.5 cm. The end, which is to be inserted into the module, will have velcro hooks for assuring the connection.

Figure 4. Power/Communications Cable Connector

The power/communications cable connector will rest on a small platform approximately 20 cm from the corner of the frame. This is to ensure that the connector will not interfere with operations involving the door and frame. The connector will simply be a 20 cm long piece of 1-inch PVC pipe. Small stabilizers, as well as internal weights and measurements of buoyancy, will be used to certify that the connector will stay in place. In the water, the connector will weigh less than 0.5 kg. The connector will have to be lifted from the platform and then placed in the appropriate port in the electronics module. It will not be attached to the platform. The connector also has two anticipated methods of movement. There will be a U-bolt on the top, horizontal surface of the connector and a PVC ring will be attached to the “back” of the connector. There will be industrial-strength velcro loops which will be attached to the other end of the connector. When correctly positioned, the velcro loops will secure the connector in the open port. A 3m length of a 16-gauge speaker wire will be used to simulate the submarine cable.

Mission Task 2

The ROV must now manually trigger a release to free an instrument package that will then float to the surface. The instrument package will be 30 cm long and constructed of 3-inch PVC pipe with end caps on both ends. The instrument package itself will be buoyant and float above the work area. The acoustic release transponder unit (Figure 5) will consist of a base, housing, and a manual release. The manual release will resemble a cotter pin, which the ROV must pull to release the instrument package. It will be a 15 cm long metal wire with a 2.5 cm loop on one end to make release easier. It will take 1 N of force to pull the pin.

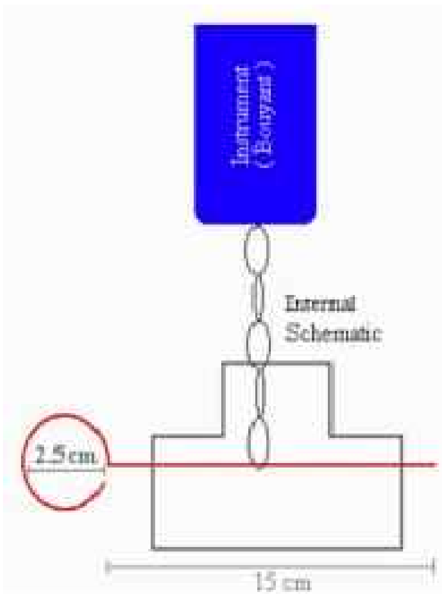

Figure 5. Malfunctioned Acoustic Transponder

The base of the housing will be securely fastened to an outcropping approximately 1m tall. The top of the outcropping will be 15 cm square. The base will be a dive weight. The weight will be attached to the housing, which will be a 3/4-inch PVC tee. The manual release will be inserted through a chain in the housing approximately 30cm long. The chain will attach to the instrument, so when the release is pulled, the instrument will be set free.

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 as well as electronics. Each separate component needed to mesh well with the other five components to produce a functional design.

Frame

The first component of the ROV was the frame design. A certain type of body was needed which would provide stability and rigidity, while reducing drag. The group decided on an open-ended box shape design to reduce drag, and allow easy access to the ROV's internal components, and to allow the ROV to hold the electronics module more securely. It also permitted the electronics module to be balance more easily since it would fit securely between the two outside U-bolts. By cutting numerous holes in the sides of the ROV to allow for motor placement and water to pass through, the ROV was able to turn much more easily. The top surface of the ROV remained intact to reduce the speed at which the ROV would sink when the electronics module is attached and the vertical motors turned off. The body was built out of Lexan since it is strong and rigid, yet it can be easily bent and molded with the proper tools.

Propulsion

The motors (Figure 6) are taken from 1250G/h Johnson bilge pumps. The group simply had to remove the bilge pump housing, attach propellers to the ends of the prop shafts, and then attach these prop shafts to the motors. Each motor draws approximately 1.3 A of current out of water and 5.8 A in water. These motors also exert a force of approximately 7 N each. We used a bollard test to determine this information (see Appendix C). To mount these motors onto the ROV each motor was first placed inside a short piece of 1 ¼ 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 then attaching these bolts to the frame.

Figure 6. Bilge Pump Motor

The group decided to use four vertical motors to create sufficient force to lift the electronics module. 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 very quickly in water and with increased maneuverability. These were positioned at each of the ROV's inside corners to provide balance an stability.

The propellers (Figure 7) used on the ROV consist of four plastic blades and are 70 mm in overall diameter. The distance across the circle 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.

Figure 7. Propeller and Shaft

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 7) 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 in competition.

- *Electronics Module Release Mechanism*

The first end effector was the electronics module release mechanism (Figure 8), designed to hold and release the electronics module. It was constructed from an electronic trunk release from a 1994 Chevrolet Lumina. 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 field passes through the solenoid, a magnetic field is produced, pulling the pin backward and releasing the latch. This function allows the ROV the transport the electronics module and release it upon command. The tool was placed in the middle of the ROV which allows the module u-bolts to be held tautly inside the ROV preventing the module from twisting. The end effector is triggered by an instantaneous switch on the control box.

Figure 8. Electronics Module Release

- *Accessing The Electronics Module*

The end effector (figure 9) was designed to open the door of the trawl resistant frame. The device used consists of a bent piece of lexan with an intricate design. Lexan was chosen for its rigidity but it could still be bent into the required shape under heat. The effector was designed to form a precisely measure L-shape instrument which would provide quick and easy access to the door handle. The effector is placed at the front of the ROV for visibility and to reduce complications and potential tangles of the tether. The effector simply hooks around the door handle and upon reverse of the horizontal thrusters it pulls the door open.

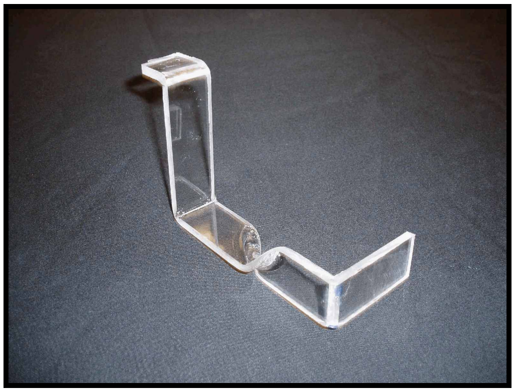

Figure 9. Door Handle Effector

- *Releasing The Acoustics Transponder*

To release the acoustics transponder, the ROV needs to remove a pin which anchors the transponder to the base. To solve this task, an effector resembling a chimney sweep was constructed (figure 10). The tool was constructed from wood, common brilliant 1"(inch) finishing nails, a 1/2"(inch) CPVC 90° elbow bend, and wood glue. The 360° peripheral design allows the pin to be hooked from any angle or direction, as opposed to approaching it from only one side. If the first approach is unsuccessful, the pilot may simply sweep in the opposite direction and once again have a clear chance to hook the pin. Placement of this tool was crucial, as it was positioned on the front middle of the ROV. This prevents it from interfering with the other effectors and still allows access to the pin.

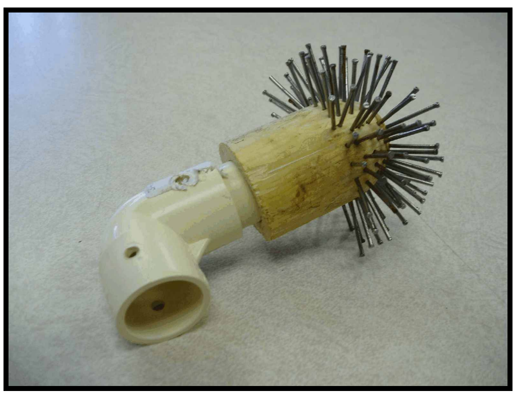

Figure 10. Pulling the Pin Mechanism

- *Power Communications Cable Connector*

The final end effector (nicknamed Texas) required a considerable amount of planning and design. It was determined that the task of quickly connecting the power/communications cable connector was crucial to completing the competition. A tool was needed which could efficiently pick up the connector, transport it, and also push the connector tightly into the electronics module's port and release it without detachment. A two-pronged mechanism was developed that would close securely over the connector (figure 11) by an automatic trigger. The tool has a guard on the front and back of the vertical attachment. The back guard can pivot on one end and is held in place on the other side by friction. It is this back guard that holds the forks open. When the forks are lowered over the connector the guard is pushed up, allowing the apparatus to close and grasp the connector. The front guard prevents the connector from moving within the claw as it pushes against the u-bolt on the top of the connector. When the ROV forces the connector into the module port it is the front guard that pushes the connector into place. However, the guard does not prevent the forks from sliding backward off of the connector, and thus the connector is released by simply driving backward.

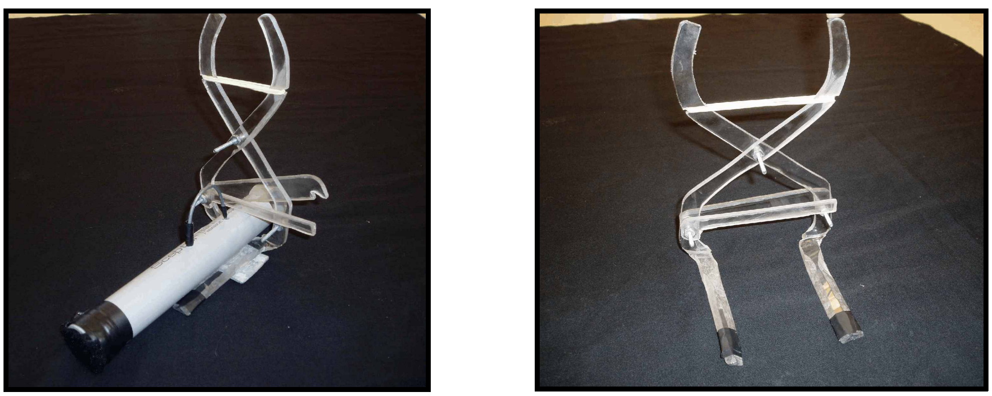

Figure 11. Texas!

Buoyancy

The final step to completing the ROV is tuning the floatation system. 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, 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 was chosen. 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.

Sensors

The only sensor placed on the ROV is the underwater camera used for navigation. Poseidon's camera (figure 12) 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 1/3" 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, 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 12. 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 systems be well arranged as well as safe to be used in water.

- *Controller*

The electronic navigation controller (figure 13) 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 as a trigger release of the communications module. The design was tested and found to allow the precision control necessary in the movement of the ROV.

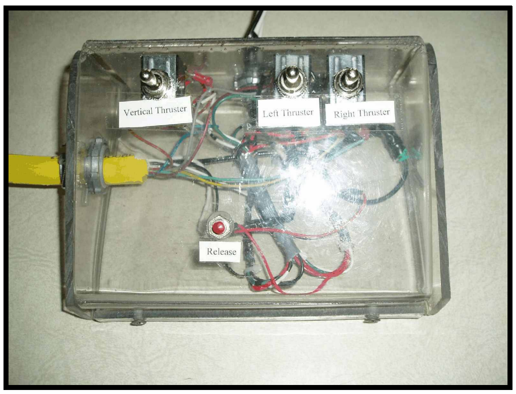

Figure 13. Navigation/Electronic Controller

- 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. 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 30 A prior to breaking the circuit.

Budget

One major factor that had to be considered was the budget (Appendix E). As this was the first year involved in the competition, many of the materials and tools needed had to be purchased. Similar to many schools within the region, Heritage Collegiate was limited in funds so 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 was also the expenses of traveling to the swimming pool for practice and to the regional competition. Overall, our total expense was $1503.46.

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 first tries to identify what exactly is causing the problem (figure 14). For example, when there was difficulty lifting the electronics module, the team studied the ROV and found that the vertical thrusters were located very close to the top surface of the electronics module. As a result, water flow past the vertical propellers was minimal since the flow was obstructed by the top surface of the module. Once the problem and its source was identified, the team brain-stormed to come up with possible solutions. From the proposed solutions the team would determine the advantages and disadvantages of each and decide which solution would work the best. To solve the problem with the vertical lift, the vertical motors were removed and re-attached at a higher point on the ROV. This reduced the obstruction to vertical water flow, which in turn increased the amount of lift, allowing us to better hold the electronics module. However, this did not provide enough lift to actually carry the module upward, so the team once again turned to the brainstorming process and decided to add two extra vertical motors.

Figure 14. Brainstorming Session

Sample Problems/Solutions

When constructing the underwater ROV, the team encountered a number of problems which could have created severe disadvantages. One of these problems was mounting the horizontal motors to the side of the ROV. As a solution, square holes were cut in the side of the ROV such that the motors and propellers could be mounted easily.

Another problem encountered was the ROV not being able to lift the Electronics Module. This was caused by the two original vertical motors pushing water from the propellers against the Electronics Module, which was obstructing water flow and reducing lift. It was determined that, even without the obstruction, two motors could not lift the electronics module. As a result, two extra vertical motors were attached slightly further out from the sides of the ROV along with the original two vertical motors.

When designing a mechanism for hoisting the Electronics Module, each team member came up with some unique ideas. However, it was the idea of the trunk release mechanism that the team was most impressed and satisfied with. When the release mechanism was obtained, it was observed that the hook inside was too small to clip to the U- bolt on the Electronics Module. A team member filed the opening so that the U- bolt was allowed to fit inside and be gripped until the release button was pressed.

When constructing the end effectors, there was difficulty designing a gripping mechanism to grab the Power/Communication Connector Cable and place it in it's destination. After a brainstorming session, the team designed a device which had the greatest likelihood of success. It worked like a claw which would clasp the cable connector when it was pushed downward against the cable connector. This would then release an elastic band, causing the claws to be forced together, gripping the cable connector. Once the connector was placed inside the electronics module, the ROV simply had to back away slowly, allowing the cable to slide out of the claw.

Figure 15. Problem Solving

Future Improvements

Presently, the ROV performs the missions and functions perfectly to the competition tasks. However, if the missions were changed and more precise movements were required, there are some minor changes that could be made. First, the horizontal propulsion motors could be angled slightly to allow for maximum water flow. This would increase the agility and overall performance of the ROV. As well, variable controls could be added so that the speed of the ROV could be adjusted in smaller increments. For this particular mission, after some great discussion the team determined that the present ROV setup would be most efficient.

Challenge

In the duration of constructing our ROV (figure 17) 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 challenge: 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 completed, but other parts of the project, such as the presentation and poster board as well. It was soon decided that much more time must be dedicated to the ROV construction. Along with the time spent during school hours it was agreed that time after school would be required to complete the ROV (Appendix F). Work during class time 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. In two days, the driver was able to complete the tasks within five minutes. The greatest challenge was overcome and we were fully prepared for the competition.

Figure 17. Planning

Petro-Canada: An organization with a similar mission

PETRO-CANADA

Petro-Canada is known as one of the largest integrated oil and gas companies in Canada, with many significant international interests. They are well-known for creating value by responsibly developing energy resources and providing world class petroleum products and services. Petro-Canada is Canada's second-largest downstream company with refining and supply operations, retail and marketing networks, and a specialty lubricants business. Its headquarters is found in Calgary, Alberta, and has 5,000 employees around the world.

Locally, Petro-Canada is the operator and 34% interest holder in the Terra Nova oil field development is 350 kilometers off the coast of Newfoundland and Labrador (Figure 18). The Terra Nova oil field was discovered in 1984 and is the second largest off Canada's East Coast. Terra Nova is the first harsh environment development in North America to use a Floating Production Storage and Offloading (FPSO) vessel. Production from the field (figure 19) began in January 2002. The Terra Nova Field has 440 million barrels of recoverable oil including 40 million barrels which will come from the Far East Development, approved in late 2005.

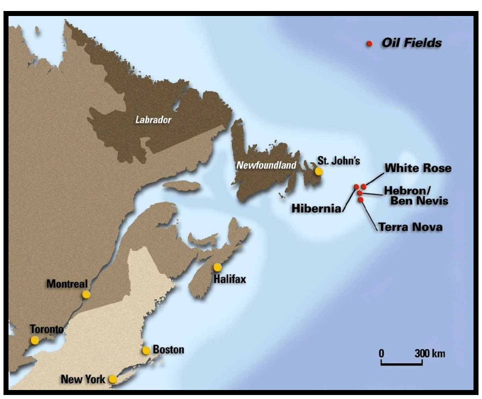

Figure 18. Terra Nova Oil Field

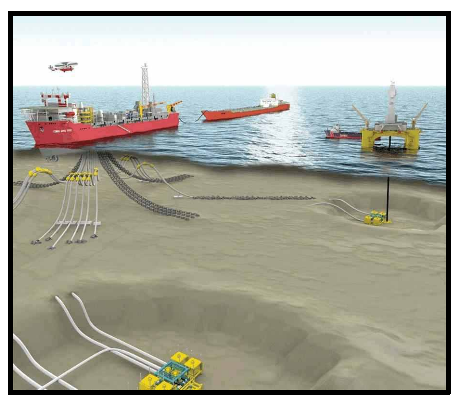

Figure 19. Terra Nova Development

Presently Petro-Canada is planning an expansion and maintenance operation for their Terra Nova Floating Production, Storage and Offloading (FPSO) vessel (Figure 20). This means entering foreign waters. The operation will take place in a shipyard in Rotterdamn, Netherlands. Since the Terra Nova has been in constant operation for several years, its hull is covered in algae, barnacles, and other ocean organisms. These creatures are very different from the organisms found in foreign waters, and could thus cause severe harm to ecosystems in these foreign areas.

Figure 20. FPSO Vessel

To prevent the aforementioned ecosystem contamination, ROVs are used to clear the ship's hull of any foreign particles. On January 29th, 2006 Petro-Canada assembled a team of expert ROV engineers, one of whom was a local man; Martin Maeland. Mr. Maeland visited the ROV team and gave an informative presentation on career opportunities in the construction and operation of underwater ROVs. Their task was to design an ROV that can scrape the algae and other organisms off of the bottom of the Terra Nova and be able to collect and dispose of it on a barge to avoid contamination of the area. The ROV must plug the valves of the FPSO from the outside to permit the engineers to operate on the inside. The ROV will be equipped with many different end effectors such as scrapers, containers, claws, and vacuums to complete its mission. The engineers have five months to complete the ROV. Martin informed our team that they will spend four months planning and only one month on its actual construction. This showed us how significant the meticulous preparation and development of ideas is before one ventures upon the ROV's construction. On June 15th the Terra Nova is scheduled to set sail and must be completely ready for its expedition.

Acknowledgments

Heritage Robotics would like to thank our team mentor, Mr. Michael Spurrell. It was the knowledge and advice of our mentor that helped us to design our ROV and his 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.

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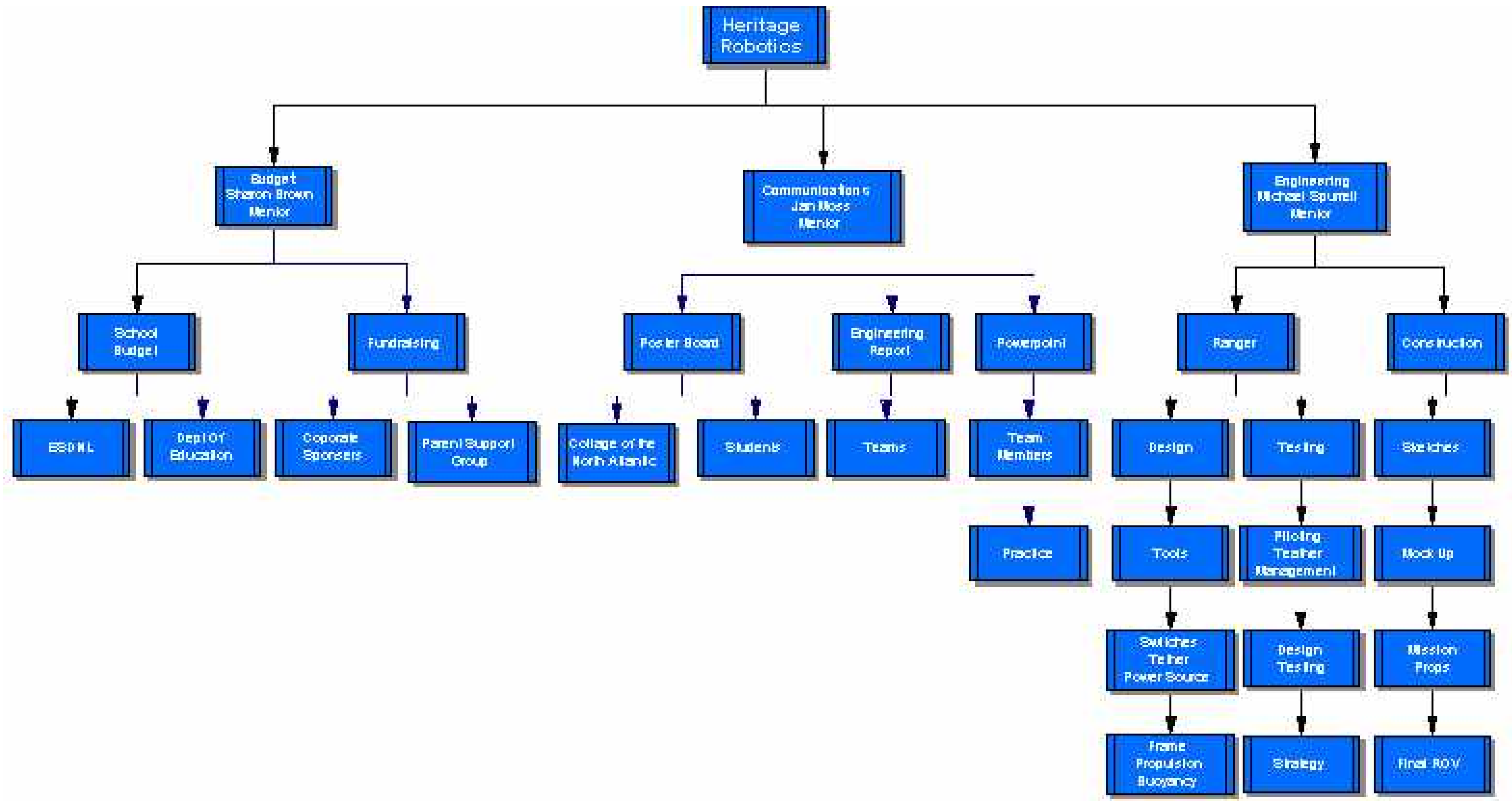
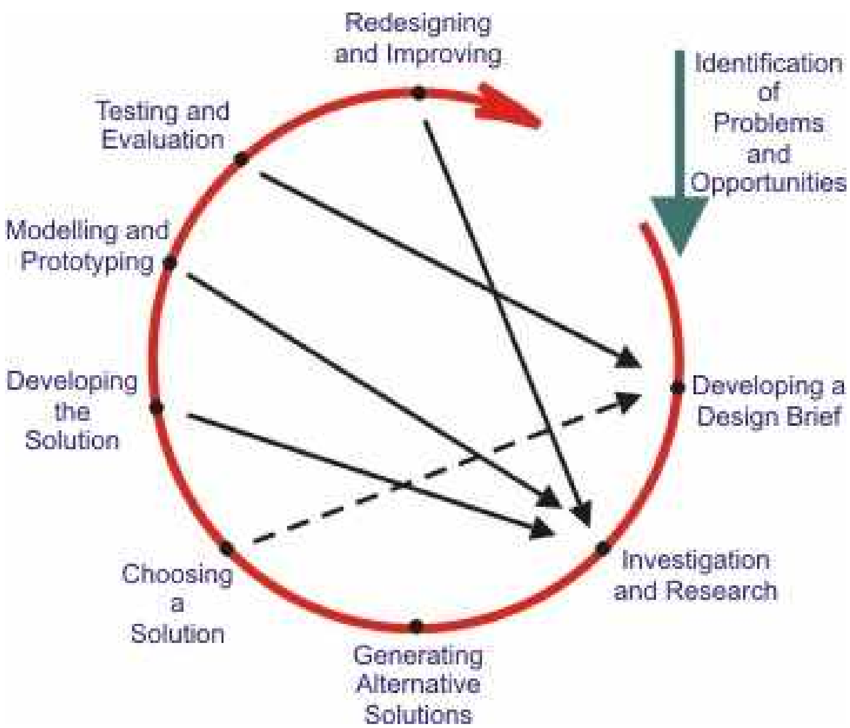
Appendix A: Team Division

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	5.9	5.5
Test 2	1.25	1.3	5.6	5.4
Test 3	1.4	1.3	5.9	5.25
Test 4	1.3	1.45	5.7	5.5

Average Submerged Forward Current = 5.8 A
Average Forward Current (Not Submerged) = 1.3 A

Average Submerged Reverse Current = 5.4 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•A = F•B
(8.5N)(0.9m)=F•(1.1m)
(8.5N)(0.9m)/(1.1m)= F
F = 6.95 N

Appendix C: Bollard Test

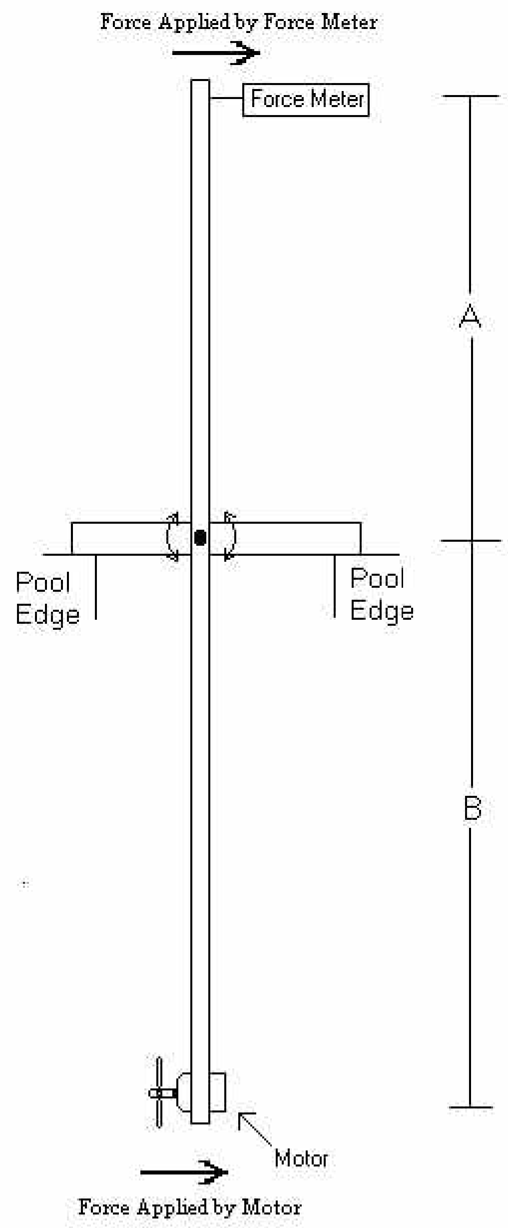


Figure 1: Bollard Test Apparatus

Appendix D: Electric Schematic

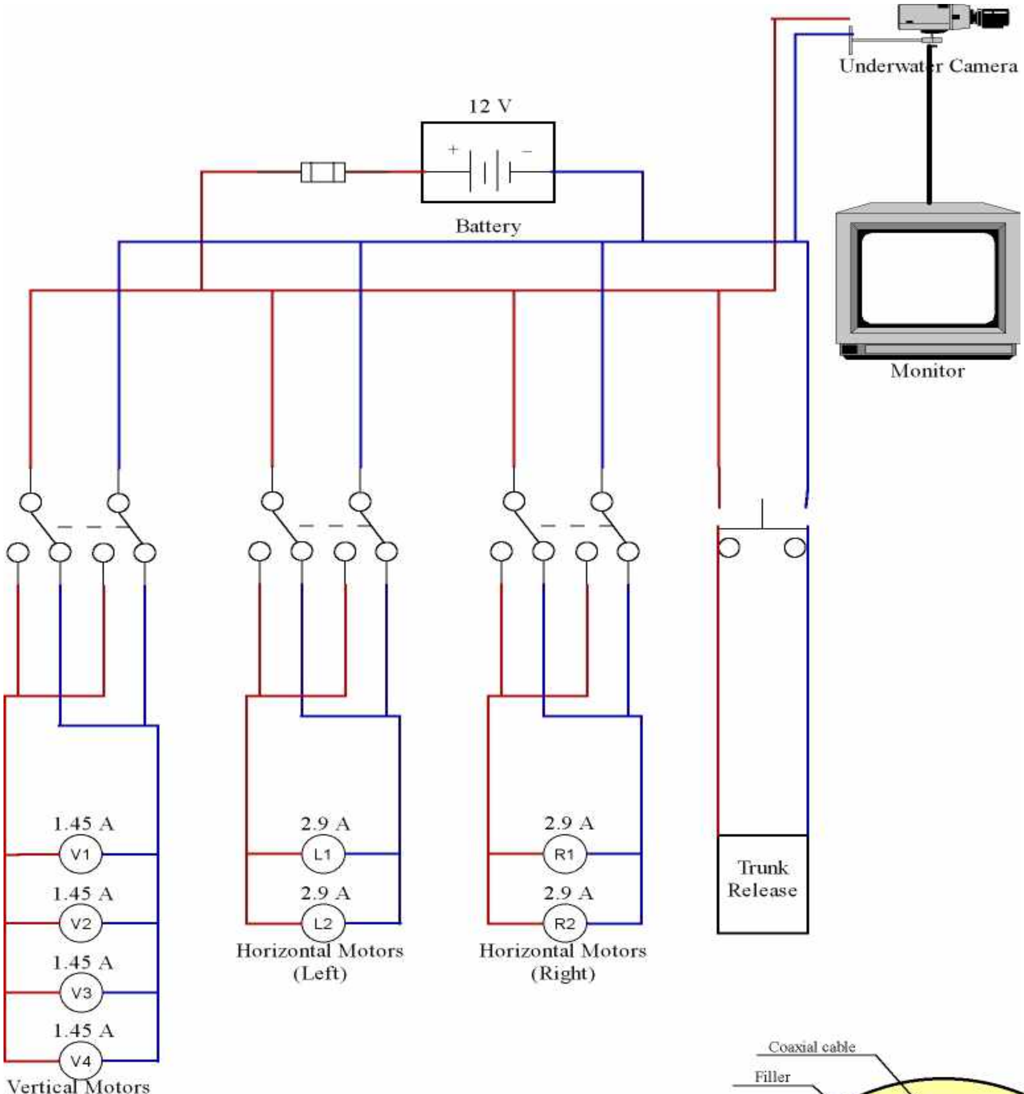


Figure 1. Schematic

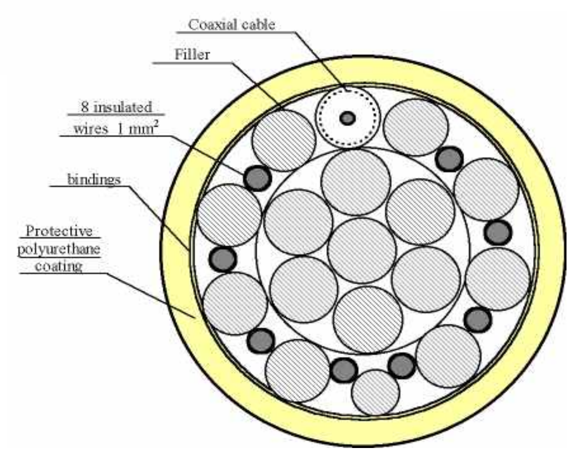


Figure 2. Tether cross-section view

MATE ROV Competition 2006

Team Name: Heritage Robotics

Budget/Expense Sheet

Mentor: Michael Spurrell

Description	Notes	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
25 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
Wood	Salvaged	1	-	$1244.26
Strip Heater	$259.00	1	$259.00	$1503.46

Appendix Working Hours Time Chart

Specified Task	02	04	06	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 →**