OD-4D

A subsidiary of

O'Donel High School

Mount Pearl, Newfoundland and Labrador, Canada

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ABSTRACT

OD-4D is a company of O'Donel High School, Mount Pearl, Newfoundland, Canada. OD-4D undertakes technology development and fabrication in the underwater environment. This Technical Report deals exclusively with our most recent project in aquatic robotics, the Remotely Operated Vehicle (ROV) ***"ICE"***. ROV ***"ICE"*** is purpose-built for shipwreck site survey, scanning, relocation of sensitive species and removal or remediation of hazardous substances. ***"ICE"***, has been designed to perform two (2) major Tasks, involving twelve (12) separate activities in a 15-minute mission on the Shipwreck Gardner, as follows:

TASK 1. Survey and assess the shipwreck site
TASK 2. Remediation of the shipwreck and removal of "fuel oil"

"ICE" was deployed as a *workclass* ROV to perform these tasks and demonstrate OD-4D's capabilities in support of a global effort of preventative remediation on recent shipwrecks.

"ICE" has a polycarbonate frame and moveable buoyancy chambers, eight 12VDC vectored thrusters, topside electronics to provide variable speed control, and onboard electronics to select visual aspect from four video cameras (including a tilting unit fabricated "in-house"). This ROV contains navigation and depth sensors to facilitate mission performance. Four payload tools are task specific, whereas two multi-function pneumatic tools: a 2-axis robotic arm and double-acting, 40 cm extension tool are used in five of the eleven mission elements. A custom-designed tether and proportional control in six axes makes ***"ICE"*** highly maneuverable. This prototype has completed all mission tasks in a time of 11 minutes 15 seconds.

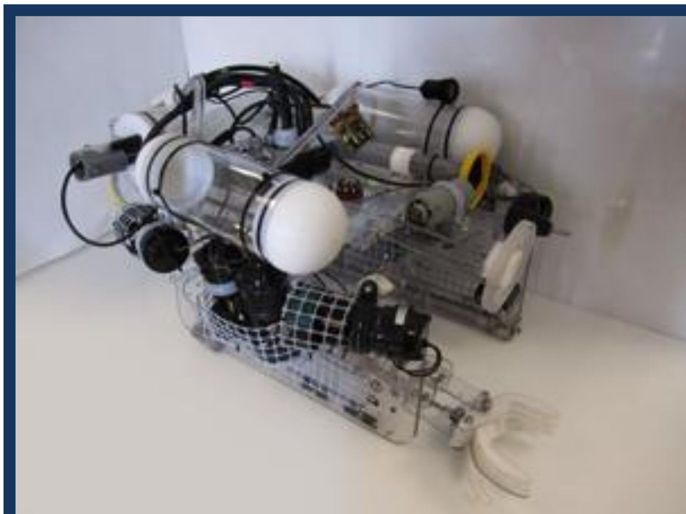

Figure 1: ROV ***"ICE"***

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1. FINCANCIAL DATA FOR PROJECT

Table 1: Total cost of materials and travel to MATE International ROV competition.

ITEM	BUDGET ($US)	DONATION ($US)	EXPENSES ($US)
MATERIALS and COMPONENTS			
Electronics can (topside and onboard)	160.00		160.00
Topside electronics: ESCs, servo controls		1350.00	1350.00
Onboard electronics: servo controls, switching	150.00		150.00
Inuktun Inc. video-cameras (2 x $1200)		2,400.00	2400.00
Tether - Leoni Elocab Inc.	250.00		250.00
Waterproof motors 12VDC (8 x $18)	144.00		144.00
Pneumatic pistons, valves, fittings and tube	270.00		270.00
Planetary Gear heads (3 x $17)	51.00		51.00
Lexan™ buoyancy tubes (5”) & end caps	89.00		89.00
Lexan™ polycarbonate sheet (4’ x 8’)	120.00		120.00
Lights, Cam., Action U/W video-camera (2)	138.00		138.00
Joystick (USB)	76.00		76.00
UW-TEC, Digital depth gauge 330m	126.00		126.00
Compass		39.00	39.00
Fasteners, drill & CNC bits, glues.	70.00		70.00
Mentor PC Netbook PC used as PLC.		669.00	669.00
SeaCon Brantner “*WetMate*™” connectors		560.00	560.00
TRAVEL			
Group airfare (17 people x $869) *est.*	14773.00		14773.00
Accommodations (17 people x $300.00) *est.*	5100.00		5100.00
Van Rental & fuel (10 days@ $55/d) *est.*	550.00		550.00
Meals: (17p x 6d x $35) *est.*	3570.00		3570.00
TOTAL	$24167	$5,018	$26785

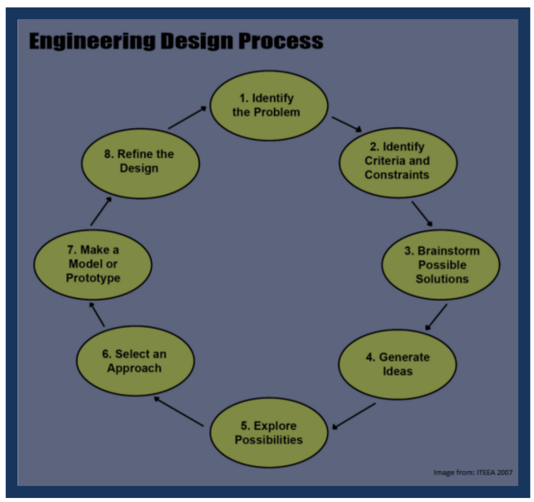
Table 2: Contributions to 4D Oceanus Robotics

CONTRIBUTORS	VALUE ($US)
Private & Gov't of Newfoundland and Labrador (NL) (Materials)	$ 750
Private & Gov't of NL via Marine Institute, MUN (Regional Winner)	$15,000
Individual contributions (17 people @ $500.00 each)	$ 8,500
TOTAL Contributions	$24,250
TOTAL Expenses	$24,167
Balance (for materials and components for 2013 competitions)	$ 83

2. DESIGN PROCESS:

The design process for ROV ***"ICE"*** follows the classic procedure illustrated in Figure 1. As always, we started with the Mission. Understanding the mission requirements and design constraints imposed by the Client, the Marine Advanced Technology Education (MATE) Center, is essential to success.

Figure 2: Engineering Design Process



The mission description and design limitations were provided by the Client in December 2012 in the form of tender documents. Members of the OD-4D design team were assigned sections of these documents for analysis and reporting, which was achieved over a two-day meeting.

During the mission analysis meetings, we brainstormed identified the following Design Specifications:

- ✓ Small size to maneuver around well-head structures;
- ✓ Adequate storage capacity for collected samples;
- ✓ Capable of multi-axis movement (5-axis: surge, roll, yaw, sway, heave);
- ✓ Capable of low-speed precision movement;
- ✓ A variety of specialized tools for efficient task performance;
- ✓ Multiple video-camera views to see a number of tool operations;.
- ✓ Additional video-cameras to provide situational awareness in close quarters;
- ✓ Combining task completion in multi-function tools to save space;
- ✓ Adequate thruster force to lift Mission Task items
- ✓ Simple, intuitive control of the operations of ROV and payload tools.

These Design Specifications guided the whole rational process of design, development, demonstration and mission task testing.

The design process is cyclical. We originally researched and brainstormed multiple design solution ideas. As new information emerges from testing, refinements in design are made. Sometimes, radical shifts in technology are adopted to improve the ROV or the payload tools it carries. One of the tools (the pneumatic arm) has undergone 12 iterations, some minor, others significant such as reducing the axes of movement for purposes of simplicity. Often these refinements are the product of our using the SCAMPER method. (http://open-your-eyes-dnt.blogspot.com/2008/08/scamper.html)

S - Substitute
C - Combine
A - Adapt
M - Modify, Magnify, Minify
P - Put to other use
E - Eliminate
R - Reverse, Re-arrange

2.1 Structural Frame

"ICE" has been engineered around the design specifications, having an open bottomed, box-shaped frame, fabricated from three pieces of 4.75 mm (3/16") thick polycarbonate plastic (Lexan™). The modular frame permits adjustments in height to accord with mission requirements and also is easily transported when disassembled. Frame size is 35 cm L x 25cm W, x 25 cm. This durable, easily cut and heat-bendable material affords:

i. a transparent structure that permits camera vision through the frame;
ii. access for ambient lighting within the frame;
iii. a large area for attachment of thrusters, cameras and payload tools;
iv. a small profile to reduce drag in forward and vertical movements;
v. a low density (ρ = 1.18 g/cm^3) material which requires little additional buoyancy;

The frame was designed in *SolidWorks*™ 3-D CAD and converted to G-code in MasterCAM, for cutting on our *RedCam*™ CNC Router. It accommodates the vectored thrusters and has bountiful space for all tools.

Buoyancy is achieved through the use of two hydrodynamic torpedo shaped acrylic air chambers (12.7 cm OD x 22 cm), each enclosing about 1.25 liters of air, are enclosed on each end by plugs CNC lathed from HDPE (high density polyethylene). The plugs have O-ring groves which seal the cylindrical end of the plug and the Lexan™ pipe. At this time, the buoyancy tubes are in line with the forward axis of the ROV and do not contain any electronics, however they have this potential in future designs. These sealed tubs have been pressure-tested at 2 ATM for one hour without detectable leaking.

2.2 Propulsion

ROV "**ICE**" is propelled by four pairs of thrusters, fabricated in our shop. *Mayfair*™ brand 1250 gph bilge pump replacement motor cartridges were used as the basis of our thrusters (*Johnson Pumps, Inc.)* . They are distributed as tabled below. (c.f. Table 3)

Table 3: Placement of paired thrusters on ROV ***"ICE"***

Port Side	**Starboard Side**
2 Horizontal Thrusters	2 Horizontal Thrusters
2 Vertical Thrusters	2 Vertical Thrusters

Figure 3: Thrusters

These thruster units have been repeatedly tested in 4m fresh water and 7m ocean

water without any detectable failure. Protective cowlings for propellers were fabricated by cutting 2" (5.08 cm) x 1.5 " ID, ABS pipe reducers and 1.5" ID ABS (Acetyl-Butyl Styrene) pipe. ABS is a tough, resilient plastic used for plumbing and transport cases.)

Each thruster motor is joined by a 1.75 cm OD x 3 cm long, cylindrical brass hub to a carbon fiber reinforced ABS plastic propeller. The propellers are 3-blade, *Grüpner*™, 60mm OD x 35 mm pitch and fit snugly inside the large end of the ABS reducer. Each thruster draws about 3.2 Amps under load at 13.5 VDC from source (12 VDC nominal), and provides 6.1 N of thrust. The voltage drops in the 18 AWG power wires, over the 14 m length of tether by 3.3V, resulting in a voltage onboard the ROV of about 10.2 VDC. (We hope to correct this deficiency in future designs.)

The horizontal thrusters are mounted on ***"ICE"*** with PVC 1.5" electrical conduit clamps, and are *torqued* laterally at 30° off the vertical plane, to avoid blocking water flow and promote turning maneuverability. The vertical thrusters are exactly that, and positioned in tandem amidships.

2.3 Videocameras

Vision is essential to complete this year's mission tasks. With multiple challenging tasks and different tools, the ROV required different cameras for specific viewing angles. Four different video cameras are securely mounted on ***"ICE".*** One of these holds a convex lens for close focus, as well as another camera which is a vertically-tilting camera.

2.3.1 Fixed position Videocameras

Nav-Cam: One *CrystalCam*™ underwater video camera is located centre aft on ***"ICE".*** It provides a view forward inside the chassis to guide movement as well as an exceptional view of most tools which are arrayed around the forward opening of the chassis. It also has the best view for scanning the hull of the shipwreck in Task 1.

Tool-Cam 1: A second *CrystalCam*™ is positioned on a 25cm high Lexan™ stalk, on top of the ROV, starboard side, looking forward to capture the operations of the pneumatic arm and the tool which captures the fallen mast.

Tool-Cam 2: A third video camera (*SS-AquaCam*™ from Lights camera Action, LLC in AZ: 400 TVL, 0.0 Lux @30cm via LED illumination) is positioned on another 25cm stalk on top of the ROV, port side, looking forward to aid in aiming both the extendable tube and compass for shipwreck orientation and the hull "drilling" penetration as well as the cap for sealing the hole in the hull, after oil extraction.

Tool-Cam 4: Finally, a fifth video camera (*SS-AquaCam*™) is positioned the port side of the ROV top panel, looking aft, to read the numbers on the measuring tape which measures the shipwreck hull length.

Compass-Cam 1. A fourth waterproof video camera (*Panvigor* ™) is mounted on a *Lexan*™ bracket , suspended from a conical rubber plug on the outer end of the extendable tube. It is positioned just 6.0 cm aft of a diver's compass and views the forward compass orientation through a side window. This camera is corrected with a 2.0 diopter convex lens to focus clearly in water on the compass window.

2.3.2 Tilting board camera

In addition to these four fixed video cameras, an in-house built; tilting camera with a 150^{o} range of vertical rotation serves as a redundant and supplemental visual system. This unit uses a 12V *Supercircuit*™ PC823UXP high resolution (460 TVL), low light (0.5 Lux) color board camera and a micro-servo for tilting it, inside a clear, 3.8 cm OD waterproof cast acrylic pipe. Its primary function is to display all the tool operations on the ROV from a different perspective than the navigation camera. This is especially important for all tasks where using the arm is necessary and more than one views are needed to provide perspective for completing precision mission tasks in 3-D space.

2.4 Electrical and Electronics

2.4.1 Topside Control Electronics

"ICE" is highly maneuverable. The topside electronic controls permit proportional control in all directions and movement in three axes, including 360° horizontal rotations and sway. The Pilot's joystick generates signals as input to a computer program written in C# which controls all ROV movement. (See Table 4. below).

We obtain proportional control through the use of four PWM (pulse width modulation) ESC (electronic speed controller) units (Victor 883s) from IFI Robotics - one for each of the four thruster pairs. The complete array of electronic components used on ROV ICE is portrayed in Figure 15 (See Appendix).

Table 4: Topside Proportional control process

Joystick control	Signal	Processor	Function
Joystick Y axis (SURGE)	Analog, Proportional	*Phidgets*™ 4-servo controller	Hor. thrusters forward and reverse
Joystick X- axis diagonal (mixes X & Y axes)	Analog Proportional	*Phidgets*™ 4-servo controller	Hor. Thrusters move ROV Stbd. or Port
Joystick Rotation (ROTATE - YAW)	Analog Proportional	*Phidgets*™ 4-servo controller	Hor. Thrusters in opposite directions
Joystick Full X (SWAY)	Analog w/ dead band.	*Phidgets*™ 4-servo controller	Vert. Thrusters move ROV Stbd. or Port
Throttle toggle (HEAVE)	Analog Proportional	*Phidgets*™ 4-servo controller	Vert. Thrusters up/ down
Left top button	Analog	*Pololu*™ 8-Servo Micro-controller	Switches on navigation camera
Right top button	Analog	*Pololu*™ 8-Servo Micro-	Switches between on side survey and tool cameras

2.4.2 Tether

The student-designed tether, produced by Leoni Elocab, in Etobicoke, ON, is almost neutrally buoyant in fresh water. It contains the following number of wires.

Table 5. Primary Tether components.

Type of conductor	Number	Size	Function
18 gauge wires	8 (4 pairs)	AWG 18	Power to four groups thrusters
18 gauge wires	2 (1 pair)	AWG 18	Power to onboard water-proof can
22 gauge shielded	2 (1 pair)	AWG 22	Serial signals to onboard can
Coax cable	1+ ground	75 Ω	Video signal to the surface

Our tether is securely attached to the ROV by one type of connector: A wet-mateable in-line connector for the thrusters. All were donated by the Canadian distributor for Seacon-Brantner, Egetech in Eobicoke, Ontario.

Most of the component wires are bound together within a single "primary" tether cable and are secured by a buoyant layer and a slick surface coating. This tether minimizes delay and instability of the ROV.

Due to the complex design of ***"ICE",*** an additional "secondary" tether had to be incorporated. It contains six (6) tiny (1/16" ID, 250 psi) air lines along the length of the tether to actuate the pneumatic tools. In addition, two additional miniature cables bring signals from an additional two cameras to the surface. Also, three 18 AWG wires are included in the secondary tether to power the onboard tools. These wires and miniature hoses are securely bundled using *SpiralWrap*™.

2.4.3 Onboard Electronics

During a calamity with a flooded electronics can in early May, 2012, excessive voltage destroyed our older, but quite serviceable, Inuktun™ 6 VDC *FireFly*™ video cameras. We have recently installed a new onboard electronics can on our ROV. It is an acrylic container with a removable waterproof lid from Ikelite™ Video Products. This container receives the tether wires and those from our cameras. It contains some basic electronics to switch video camera signals and shunt them up the tether to be viewed on the surface.

In the waterproof electronics “can” the primary 12 VDC power wires are split to provide 5 and 6 V regulated power to other devices using *FirmtronicsTM* Battery Elimination Circuits (BECs).

These electronics are used for the exclusive purpose of powering and selecting one of the three video camera signals to send up the coax cable in the tether for viewing on the surface.

The video signal switching is achieved by operating three electronically controlled *Dimension Engineering*™ “Battleswitches” - one which switches signals between the navigation and tool camera 1 and the second which toggles between the two other tool cameras.

Table 6. Electronics components and function in onboard can

Voltage	Source	Destination	Purpose
12V	Direct from tether	*Pololu*™ 8-port Servo controller	Provides 12 VDC power to: i. *Pololu*™ 8-port servo controller, ii. ‘Board’ video-camera iii. 6V DC S-BEC regulators
6V	S-BEC switching regulator (yellow)	*Pololu*™ 8-port Servo controller for output signal	Powers the two (2) Dimension Engineering™ “Battleswitch”s one which selects video signals from two (2) onboard video-cameras and the other which turns on valve wheel rotator tool.
5V	S-BEC switching regulator (blue)	Video cameras	Powers video-cameras and LED lights

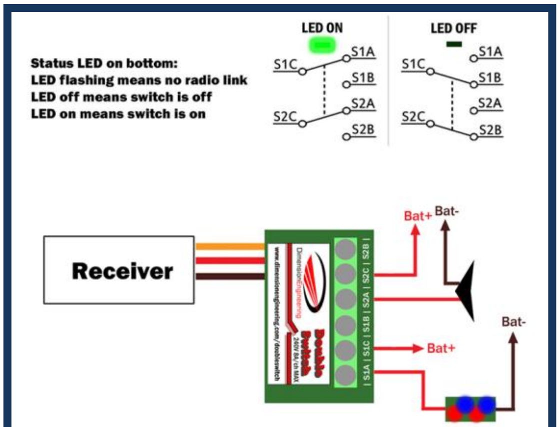


Figure 4: Wiring Diagram: video signal switching

These electronic solenoid switches can handle up to 60 Amps.

The “Battleswitches” are controlled by a serial signal sent from the joystick and computer (topside) to a *Pololu*™ brand 8-port servo controller in a waterproof box (“can”) onboard the ROV. The critical technology which enables us to safely use a submerged electronics “can” are water-proof bulkhead electrical connectors donated by *Sea-Con - Brantner*™.

2.4.4 Software

Our control design uses a PC laptop as a Programmable Logic Controller (PLC) for the operation of the electronics components described above. We have used C# programming to operate these electronics.

C# programming was chosen as:

i. It is a more widely used language in industry and research, than Visual Basic, which is more commonly used in our schools.
ii. It was free, which helped to keep our costs down
iii. C# has enormous support from electronics suppliers and is widely used as an interface program for electronics components
iv. It is part of the family of programs based on .NET technology

Nevertheless, C# is not taught in schools in our region and we had to learn most of it on our own. We learned C# through printed manuals and on-line tutorials. The code in C# was designed by students, with some guidance from senior students. The code was segregated in functional libraries, to permit ease of selecting code for the use of different tools.

Given that we were novices, we were looking for simple solutions. We discovered stock programming (API's) from electronic component suppliers and MS.NET libraries such as DirectX.

i. Stock programming in C# for the multi-function, USB joystick we used was found as a compiled program from MS DirectX.
ii. The *Phidgets*™ 4-servo motor controller has a C# compiled program available from the supplier.

Our programming is broken into three sections:

i. Input operations
ii. Processing operations
iii. Output operations

Input Operations:

The only input operations on ***"ICE"*** are those derived from the joystick. The signal range in all axes is between -250 and +250 is a dead band to eliminate overly sensitive joystick movements.

Output Operations:

Forward and reverse thruster operations involve the same values of signal throughout the full range (150-1000) in both Starboard and Port horizontal thrusters.

Mixing the ranges of horizontal thrusters (ex. +500 in the Port and +200 in the Starboard thruster) results in the thrusters rotating in opposite directions and the ROV moving in a forward arc.

The signal values of -500 in the Port thruster and + 500 in the Starboard thruster (from rotating the joystick, results in a rotation of the ROV to Port, within the ROV footprint.

Using reverse directions of thrust for the vertical thrusters on either side of the ROV , results in a SWAY movement….permitting sideways movement in either Port or Starboard direction. This function can be turned off when not required. In addition, several of the joystick buttons are used to select the video feeds onboard the ROV which are sent to the surface monitors.

2.5 Safety Features and Precautions

Safety was always an important factor throughout the building, testing, and operational process of the ROV. All members were instructed to use power tools safely and were always supervised while operating drills, irons, saws, etc

ROV ***"ICE"*** has a number of safety features, including:

i. Circuit breaker protection (25A) on the positive power feed, combined as a kill switch for emergency stoppage;
ii. Protective thruster cowlings to avoid wire entanglement and injury;
iii. Rounding and removal of all sharp edges;
iv. Complete Potting of electrical connections and components in onboard electronics boxes and motor containments;
v. Use of "*WetMateable*"™ SeaCon Brantner, Inc. electrical connectors to prevent water entry;
vi. Secure tether attachment and strain relief to avoid breakage or damage;
vii. A master valve cuts to pressurize the pneumatic robot arm until the ROV is "away" and on Mission;
viii. An output air pressure gauge ensures compliance with specified limits;
ix. Warning symbols or signs located on thrusters.

Operational safety procedures include:

i. Safe practices were developed for transporting the ROV and auxiliary equipment on a wheeled cart;
ii. A staff member was "Safety Point" when the Deck Team procession moved;
iii. A pre-dive check protocol requires "Power off", except when "All-clear" is designated by the deck manager;
iv. PFDs are worn by all deck crew during testing and competition;
v. Command Instructions used on deck have been defined and are used;
vi. Careful stowage, deployment and management of the tether during mission

3.0 PAYLOAD TOOLS:

Purpose-built tools were uniquely designed for the tasks in the 2012 mission. The complex, multi-step tasks required a number of different tools. With limited space onboard the ROV; some tools were designed for multiple functions. Some tools require actuation using surface-supplied pneumatic air pressure, some require electricity, and some are mechanical.

3.1 TASK ONE: Survey the Shipwreck

Step One: Measure the overall length of wreck.

For this task we use a Metric/SAE industrial measuring tape mounted to the chassis on the top of the ROV. The measuring tape has an 11.43 cm diameter High density polyethylene (HDPE) ring with an indented cove, the diameter of a ½" ID PVC pipe, in the front. The ROV flies over bow of the shipwreck hull, slips the ring over measurement post, reverses thrust until the other measurement post is in sight and then read the distance from the measuring tape through a video camera. The diameter of the HDPE ring is 11.43cm is subtracted from the recorded measurement.

Step Two: Find the orientation of the ship.

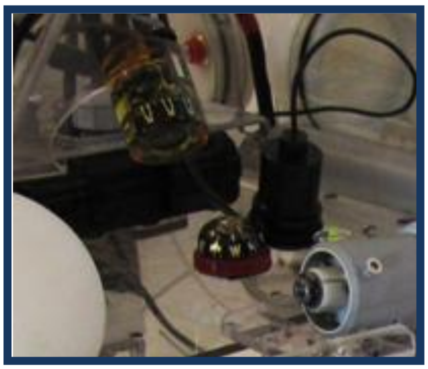


Figure 5: Compass

This task is used to help pinpoint the exact compass orientation of the shipwreck for mapping purposes.

For this task we use a diver's compass with a side viewing window. The compass is mounted on a Lexan™ bracket 16.5 cm by 5 cm, suspended 17 cm from a rubber cone, located on an extendable 6mm OD stainless steel tube. To find the orientation we fly above the wreck and extend a horizontal pneumatic actuator 40 cm to avoid the influence of the magnets in our thrusters. Once the actuator is extended a reading is taken along the line between the measurement posts.

Step Three: Determine if the debris piles are metal or non-metal.

Two, 15.24cm rubber tubes, with rare earth magnets at one end are attached to a thin wand of HDPE 8 cm L x 25.4 cm W x 0.3 cm thick, mounted 5 cm below the chassis. The magnets are dragged over the debris props. When they attach to a metallic pile, the rubber tubes stretch quite visibly.

Step Four: Correctly scanning the ship at two target locations.

The ROV ***"ICE"*** uses its navigation video camera to survey the hull for damages or cracks. The ROV hovers with the camera at 45 cm from the bottom at 1.5 m back from the hull for 10 seconds.

3.2 TASK TWO: Removing the fuel oil from the shipwreck

Step One: Transport and attach a lift bag to the U-bolt on the 'fallen mast'

Figure 6: Happy Hooker

The device for this task consists of an array of four horizontally guided carabineers on a 17 cm by 7.5 cm Lexan™ bracket, connected to a 23 cm long piece of ½" Polyvinyl chloride (PVC) pipe. A stainless steel eye bolt, screwed into the top of the PVC pipe holds another carabineer which attaches to a "lift bag". This device is called the "Happy Hooker (HH!!:<)". The HH and lift bag are held n position by the pneumatic arm. One or more carabineers is pushed onto the U-bolt , the arm's claw opens and the lift bag is inflated from the surface and rises.

Step Two: Removing and transplanting endangered corals from the hull

This task uses our multi-function, two-axis, pneumatic arm. The structural frame of this arm was fabricated with clear Lexan™ plate, cut to size, and white Lexan™ claws on the gripper for so it can be seen easily with our cameras. The lower arm can be raised over a 45 degree range from horizontal by a dual-acting stainless steel SMC™ cylinder of 1.42 cm bore and 3.8 cm stroke. The gripper is operated by a single-acting, spring open, Parker™ stainless steel pneumatic cylinder with 1.90 cm bore and 3.8 cm stroke. The ROV picks up the corals with the pneumatic claw and then relocates them in an open space on the plastic pipe grid. Both corals are transported at the same time. The opening claw is a flawless, positive release mechanism

Step Three: Verify if there is hazardous fuel in the hull.

The sensor module for this task is a 10 cm diameter 1 cm wide Lexan™ open circle, within which, on the same face plane, is a smaller 3 cm HDPE disk, representing both sensors. The sensors are carried outside the port side of the ROV and are deployed as a single unit, beyond the range of other tools, by swinging laterally to point fully forward. A miniature waterproof motor attached to a planetary gear head actuates this movement.

Step Four: Drilling the hull

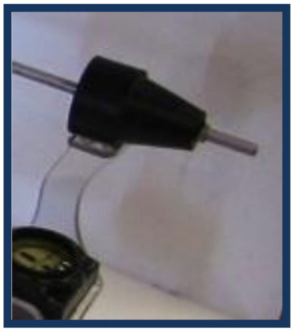


Figure 7: Hull Penetrator

We simulate drilling the shipwreck hull by inserting a stainless steel tube with an internal diameter (ID) of 4.63 mm through a Vaseline filled aperture in the mock shipwreck hull. A stainless steel pneumatic cylinder (2.54 cm bore ; 35 cm stroke) pushes this small bore tube forward on the Port side of the ROV. This tube is guided through an HDPE channel, mounted on the roof of the ROV. On the front end of the tube is a rubber cone which seals against the hole in the shipwreck hull. On the tip of the cone is a flexible seal (from a Gatorade cap) which prevents Vaseline from entering the tube.

This rubber cone seals tightly around the stainless tube but is lubricated with silicon grease to permit the tube to slide through it into the oil reservoir when the pneumatic cylinder is actuated. This was a perfect solution to prevent leakage of the "fuel oil" inside the hull.

The aft end of the stainless steel tube is connected to a clear plastic hose which attaches to the bulkhead fitting on one end of the vacuum pump used to suck the "fuel oil" from the hull.

Step Five: Extracting an oil sample

The vacuum pump is a 10.2 cm ID clear Lexan™ pipe, with HDPE end caps, sealed by O-rings. The plastic tube from the stainless steel penetrator enters on one end through a bulkhead watertight fitting. It is connected inside the pipe to a tough plastic, urostomy bag with a one-way valve in the inflow and a small plastic cap on the outflow. On then end cap opposite the inflow, is mounted a small 300gph (2.5 A) bilge pump which sucks water out of the Lexan™ pipe. Starting the pump produces a negative pressure inside the Lexan™ pipe. The negative pressure opens up the urostomy bag which sucks the "fuel oil" from the tank inside the mock "hull"; filling the bag. The apparatus extracts 400 ml of undiluted "fuel oil" in eight (8) seconds of operation.

Figure 8: Fuel Oil Vacuum

Step Six: Capping the well

Following the "fuel oil" extraction, the hole in the hull must be sealed using a cap prescribed and provided by the Client (MATE Centre). This cap is held on ROV ***"ICE"*** by a specialized tool consisting of a 20 cm long piece of PVC pipe in which 12 radial slits have been cut. The slits open when the cap handle is inserted and holds the cap handle by friction. For additional security, an O-ring encircles the slit section of the pipe. The ROV simply flies the cap onto the drilled hole and the loop Velcro, on the lip of the hole, locks into the Velcro hooks on the cap. The ROV reverses and the cap is freed.

4. Challenges

Throughout the design and construction of the ROV, our team faced multiple challenges. Most of these challenges emerged through the design process, or with continual refinements in tool design…..and one catastrophe.

One significant problem which was immediately discovered was the difficulty of using a compass within the array of thruster field magnets. Experiments revealed that the compass needed to be at least 40 cm outside the ROV to provide accurate readings. We examined several methods of removing the compass from the ROV and after many trials selected a 45 cm stroke pneumatic cylinder.

It soon became clear that this same device also offered the opportunity to penetrate the mock "hull" of the shipwreck to pump out the "fuel oil". This insertion method does not rely only on sealing the mouth of the hole for "fuel oil" extraction, but inserts the collection tube inside the "fuel oil" reservoir.

It was also possible that the compass now offered a completely separate method of identifying the metallic debris in the shipwreck debris field. This was tested and proved quite functional.

We had a major issue occur just a few days before the Regional ROV Competition as our entire onboard electronics and cameras were short-circuited by water infiltration during a test run.

5. Troubleshooting Techniques

Trouble shooting techniques tend to be domain specific. They differ depending on the environment, issue, process being affected. Generally, they are only realistic having knowledge or experience with the system in question. We had an issue with our capability of collecting the oil from the tank of the ship; we needed to find a way to extend our extraction rod. We also had difficulty with our pump, for it needed to be primed, which contributed to dilution of the sample. We also had a major issue with our onboard electronic can short-circuiting during a test the week of our regional competition. We used the KISS Principle as the method of analyzing the problem…starting from simple causes and proposing simple solutions..

Extending the Extraction Tube

1. We explored the concept of using a pneumatic cylinder to extend a 4.6 mm ID stainless steel tube from the ROV.
2. We thought of ways in which the rod could be attached, mounted and positioned.
3. We attached the tube below the top of the ROV frame, connected to the pneumatic cylinder directly below.
4. Next we tested aiming the rod into the ships “fuel oil” tank.
5. It was found that aiming the rod into the tank was a very difficult task, for there was a small ledge inside the opening of the tank.
6. We added a short section of ½” ID PVC pipe into the conical rubber plug which perfectly guides the “fuel oil” extraction tube into the tank.
7. We then added the valve tip from a Gatorade bottle to the forward end of the rubber cone, to prevent Vaseline from blocking the tube end, prior to extraction.

Priming the Pump

1. Our fuel oil extraction apparatus has a long but small diameter bore (4.6 mm ID) stainless steel extraction, joined to a flexible hose. The volume inside this apparatus would permit a dilution of the required 100 ml “fuel oil” during extraction.

2. We also remembered that in the tank there are 1000 ml of oil, therefore trying to extract more than 1000 ml would be redundant.

3. Consequently we redesigned this apparatus to collect a full liter (1000 ml) of the “fuel oil” such that the dilution effect was minimized.

4. In testing we timed how long it would take out primed bilge pump to pump the whole 1000ml of oil from the tank, so we could use this amount of time for pumping, without the need to have a camera to view the collection bag.

Onboard Electronics

1. With the short-circuited onboard electronics can, our superb Inuktun cameras were dead. Therefore we had to find a way to set up cameras without our can.

2. We quickly obtained another set of cameras quite cheap waterproof video cameras that we could use for the competition

3. But instead of feeding the video signal through the tether as originally planned, we had to attach more wires to the outside of our primary tether.
4. This method worked out well for the time that we had to address the problem, although it made the job of our tether managers more difficult, as they had more than our traditional tether to work with.
5. After the regional we decided to fix the problem by using a Ikelite™ acrylic waterproof video camera box as our electronics can. This allowed us to send the video signals back up the tether as originally planned. This work is currently in progress.

6.0 FUTURE IMPROVEMENT

OD-4D has a history of technical excellence, but to remain competitive, we recognize that our potential clients require that the level of ROV technology must be of a high standard, and so our service must keep improving.

The firm had significant plans for enhancing the technology used in our ROV ***"ICE"*** this year, but we were hampered by the availability of funds. We set two goals in light of this reality. We had to secure funding to acquire the new technology which we hoped to add to our ROV, and we had to design around the limitations of our current model. These limitations were as follows:

6.1 Robotic Arm

Our current robotic arm is powered by pneumatics (compressed air) from the surface. We are limited to 40psi air pressure at the surface and this working air pressure is considerably decreased with greater depths of water in which the mission is to be conducted. A further complication is that each pneumatic cylinder used onboard the ROV needs a minimum of one airline (single-acting, spring return) or two airlines (double-acting). In order to increase the number of axes of movement of this arm to enable more precise and varied movements, the number of air lines running down our tether becomes unwieldy. We examined three alternatives to overcome these limitations:

Figure 9: Robotic Arm Gripper

i. Reducing and simplifying the robotic arm to reduce the numbers of air lines;
ii. Distributing the air from a single line, onboard the ROV, using solenoid valves;
iii. Converting from pneumatic to low pressure hydraulic power onboard the ROV

6.2 Electronics Onboard

The second and third solutions identified above, all require onboard distribution of power and control signals. Currently, our tether is unable to carry more than a serial signal down a shielded twisted pair of AWG 22 wires. If we were to place control of some fluid power onboard, the control of these solenoid valves would be difficult due to the control limitations. We have devised solutions to the two significant problems described above.

6.3 Finances

The team, this year, accepted responsibility for all the recycling in the school and has been earning modest but consistent amounts of funding for this rather smelly task. The fund-raising is slow but assured. There will be adequate capital in our budget for next year's improvements. ***"Where there's muck; there's brass!"*** Yorkshire Proverb

6.4 Future Technical Improvements

A significant part of our effort this year has been researching for the future. We have been researching a new design that will improve performance in several areas. This new design requires new components, which fortunately by Autumn 2012 we will have. The new design will include:

i. A tether which includes a single pair of power wires; an imbedded Ethernet cable and a 75 Ω coax cable. It will be smaller in diameter, lighter, and more flexible than our current tether. It will also enable significant expansion of our power and signal distribution from the ROV.

ii. A high quality enclosed waterproof "can" in which to contain onboard electronics.

iii. Some commercial grade (expensive) bulkhead penetrating connectors to enable power and signal distribution outside the waterproof can.

iv. The use of USB-format electronics line which are controlled through the Ethernet cable to permit multiple control of thrusters, payload tools and sensor input and movement up the tether.

v. Some miniature low pressure hydraulic equipment to actuate the robotic arm and other linear actuators. It will not require surface pressure and could use ambient water as the fluid power. This remains a challenge in locating miniature equipment in the tank.

7. LESSONS LEARNED

The research required for planning this and next year's ROV exposed the entire staff to a host of new skill sets and materials science. Some of these are described in the section above. Perhaps the most useful technical skills were those required for the design of components of the ROV using CAD (Solidworks™) and the conversion of these visual products in Master CAM™ to the codes required to operate our CNC router. It is a very powerful tool and capability. We have had visitors from other schools attending this competition who have come to our school to lean the use of this equipment and to fabricate some of their own ROVs.

However, the most important lessons learned – those which we will carry with us for the rest of our lives were affective outcomes. Affective outcomes are those which affect our way of looking at the world; our way of learning or *epistemology*, and our way of organizing and management. Examples are as follows:

i. We understand the world as a much larger place with greater diversity of abilities, beliefs and cultures. We have started to realize the enormous amount of opportunities that lie beyond our island shores and also the unique lifestyle and career options within technical fields that are right here at home.
ii. We have learned that learning by the book is but one way, and that the problem-solving approach to learning is an excellent preparation for dealing with the issues of an adult world. We have come closer to realizing the value of the Chinese proverb: *"What I hear, I forget; what I see, I remember; what I do, I understand."*
iii. We have come to realize the essential skills of planning and organization require time and resource management as the foundation for success in out post-secondary academic life and in our future careers.

8. REFLECTIONS

As a company we have learned and accomplished a lot as a result of participation in this year's ROV competition. With a team comprised of mostly new members, we spent a lot of time educating new members on the design process and showing them the ropes of competing.

The members of our company's deck crew gained experience while operating under time restraints, and in an actual pool of significant depth. This allowed our deck crew to feel to stress of competition, and we as a company, were able to evaluate how we worked as a team, and how we worked in high stress situations.

What we also accomplished, from rigorous practice, was a strong engineering panel presentation where we scored eighty-three points out of a total of eighty. Every member of our company feels as if we have done very well in our presentation and have really proven our proficiency in this area. One important thing our company has gained from a judged evaluation is confidence! We've discovered that our practice has really paid off and that if we continue to practice we will do just as well in future presentations.

9. TEAMWORK

The firm's organization focused on the four major requirements of the competition: ROV Performance, Engineering Panel, Poster Presentation, and Technical Report. Project management (of materials, people, and work) was enhanced by using MS Project software.

Figure 10: Team Photo

Missing from photo: Christina Hamlyn, Kristen Marks

With a large number of team members it was necessary to break off into smaller groups. It was difficult to assign anyone to a single role; therefore we contributed to whatever was needed and this made for a fluid movement of team members. The good thing was that we gained many skills and experiences which we would not, had we been relegated to single tasks.

Small groups took ownership of the design of the ROV and multiple tools. However, these tools had to fit together on a single small frame, and communication between the groups was critical to brainstorm solutions. We did this by having review and planning sessions at the beginning and ending of every meeting to keep team members up to date with the most recent design changes and priority work commitments. The group really knit together as a team in two different environments.
Team building:

We had team-building sessions at the beginning of our meetings this year as a method of "ice-breaking" and rapidly becoming comfortable with each other. We also were encouraged to try SCUBA Diving by our mentors."Just to get a feel for the environment in which the ROV operates." It was activities such as these that developed the following code of ethics of our team:

i. We will help one another, particularly in areas where I am strong and they are not;
ii. We will not criticize the efforts of others, but encourage them;
iii. No idea is stupid…all may blossom into something great;
iv. We will expect the best from us all and we will each demonstrate our commitment.

Competition:

It was remarkable how we seemed to become a closer unit during the recent Regional competition. It was if "trial by fire" forged our relationships. It was undoubtedly because we all faced the same fears and challenges.

10.0 ACKNOLEGDEMENTS

We would like to thank the following contributors and individuals for their contributions. Without their support we would have been unable to participate in this year's MATE competition and our ROV would not be of the caliber that it is today. A special thanks to the Eastern School District of Newfoundland and Labrador for use of their facilities and mentor guidance.

10.1 Financial Contributors and Donations in Kind

Table 7. Financial Contributors

Contributor	Type
Business, Innovation, Trade and Rural Development (NL)	**Financial**
Exxon Mobil	**Financial**
Statoil	**Financial**
Inuktun Ltd, Port Moody, BC	**Donation (U/W Cameras)**
Phidgets Inc. , Calgary, AB	**Donation (Electronics)**
SeaCon Branter, Santa Barbara, CA	**Donation (U/W Connectors)**
Mayfair Marine, Johnson Pumps, Chicago, IL	**Discount (Thruster motors)**
Thomas Glass, Mt. Pearl, NL	**Discount (Plastics)**
ProArc Fabrication, Mt. Pearl, NL	**Service (tapping oil can)**
Eastern School District, St. John's, NL	**Facilities (School workshops)**
Marine Institute, MUN, St. John's, NL	**Facilities (Test tank)**

APPENDIX 1.

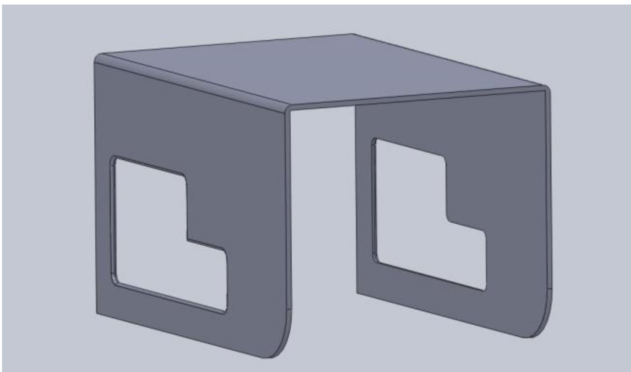


Figure. 11: Solidworks Drawing: Lexan ROV Frame

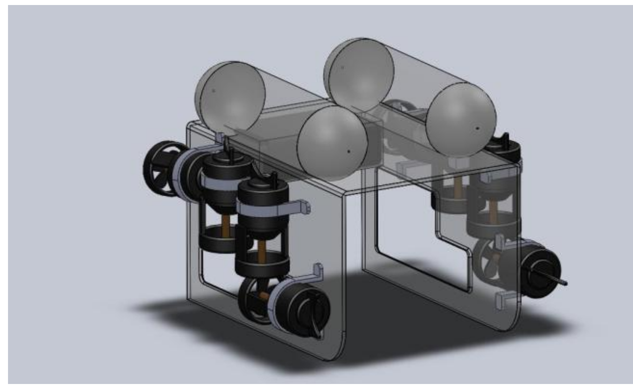
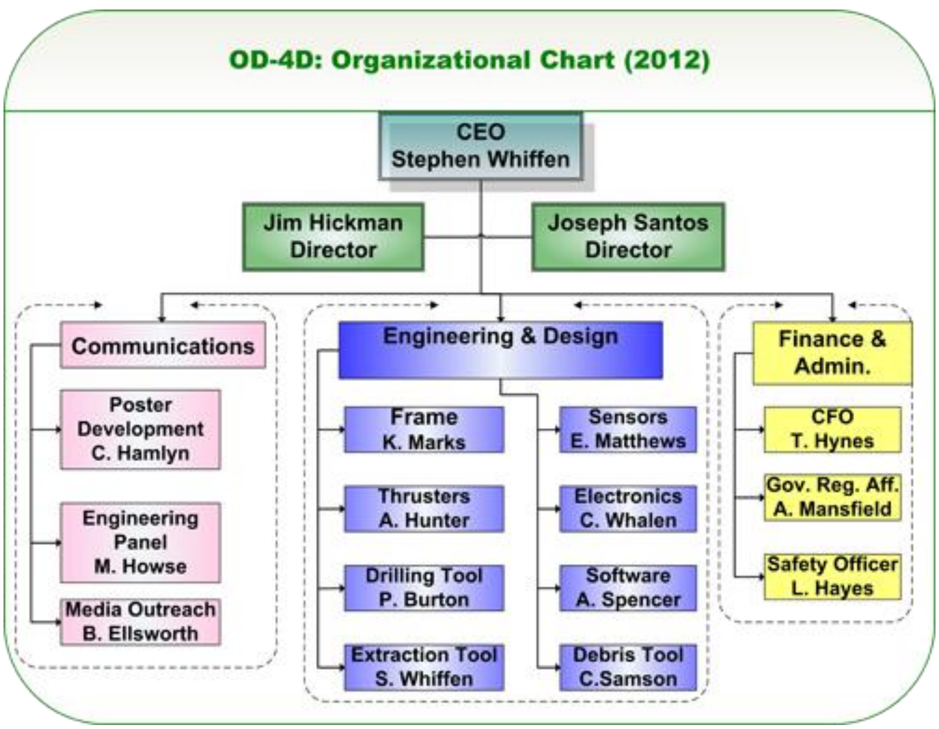


Figure 12. Solidworks Drawing: Full Assembly

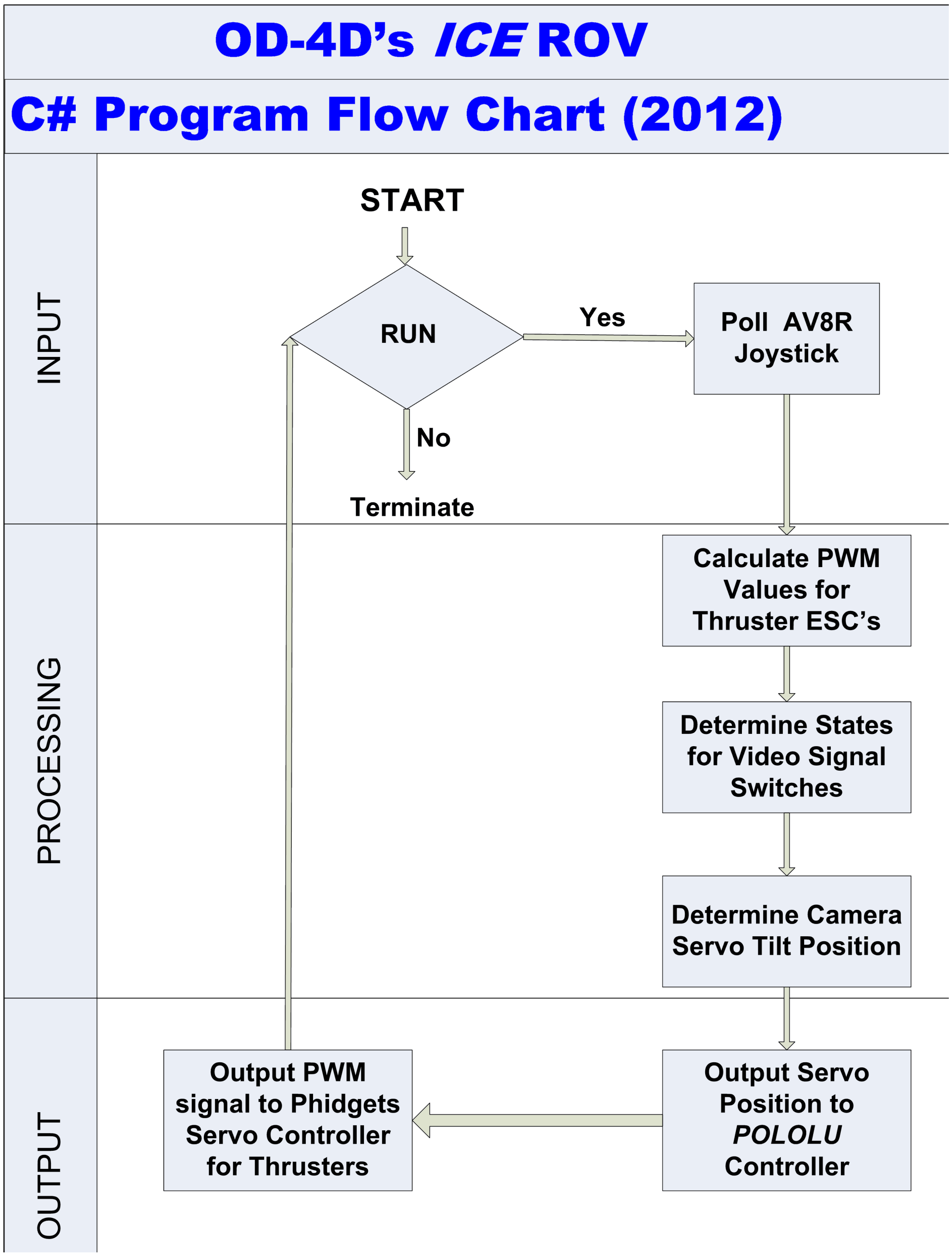
APPENDIX 2.

Figure 13: Organizational Chart



APPENDIX 3.

Figure 14: Program Flow Chart



APPENDIX 4.

Figure 15: Electrical Schematic