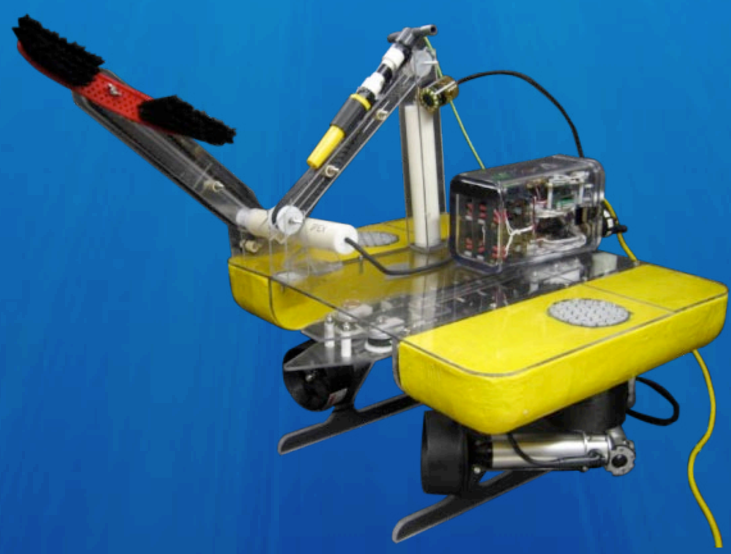
TECHNICAL REPORT

Eastern Edge Robotics Team
Marine Institute and Memorial University, Newfoundland and Labrador

2009 MATE International ROV Competition
Explorer Class

ROV Chimaera



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ABSTRACT

This technical report describes the ROV *Chimaera*, built by the Eastern Edge Robotics Team to compete in the 2009 MATE International ROV Competition. *Chimaera* was designed to perform tasks relevant to submarine rescue, such as mating to a submarine's escape hatch and delivery of Emergency Life Support System (ELSS) pods. The process of building the ROV and traveling to the MATE Competition cost approximately $50,000, including the value of donated materials. Two pontoons connected by a Lexan™ frame form the basis of the chassis, which integrates six 48V thrusters and three high quality, low-light PCB cameras. Also incorporated are four main payload tools: an ABS ring with a clear Lexan™ cap, guides and legs for opening the ELSS hatch and RORV mating, a toothed conveyer belt for collection of the ELSS pods, a magnetically coupled timing belt for delivery of the airline, and a belt-driven rotary brush for manipulation of the air valve. The control system was programmed in C# and runs using eight threads that sample data continuously. The ROV has an onboard electronics system that is inside polycarbonate housing connected to the surface using a custom-built tether. The topsides electronics consists of a joystick and a control unit. A major innovation this year was the building of our own PIC embedded motor controllers for use with the payload tools. During this process, team members learned the importance of multiple points of view in solving a problem creatively, and the benefits of working with people from many different disciplines.

Figure 1. Eastern Edge Robotics Team, 2009.
Left to Right: (back row) Justin Higdon, Jake Bragg, Matthew Miné-Goldring, Steve Crewe, Cait Button, Josh Barnes, John Hillier, Nathan Smith, Jon Watson, Scott Follett, Andrew Furneaux; (front row) Dave Hornell, Leanne Brockerville, Erin Waterman, Jonathan Howse, Mark Flynn, Travis Gosse, Max Deutsch.

TABLE OF CONTENTS

1. BUDGET AND FINANCIAL STATEMENT

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

ITEM	DONATIONS ($CAD)	EXPENDITURES ($CAD)
Polycarbonate electronics can		250.00
Electronics housing		250.00
Styrofoam		43.00
Fiberglass and epoxy		270.00
Hardware (fasteners, drill bits, etc.)		500.00
Inuktun thrusters (6 x $ 2000)	12,000.00	
48V Maxon motors (6 x$516)		3100.00
Fiber-optic tether - LeoniElocab	1200.00	
Cameras (3 x $1500)	4500.00	
Analog input board		150.00
Servo controller board		50.00
Fiber-optic interface board – Focal Technologies - Moog	3500.00	
Lexan polycarbonate sheet		250.00
Printed Circuit Board production		200.00
Pulse width modulators (6 x $250)		1500.00
Misc. electronics components		300.00
Pressure Sensor – Keller America	575.00	
Digital Compass		300.00
SubConn Connectors	800.00	
Group airfare (15 people x $480)		7200.00
Accommodations, meals, ground transportation (15 people x $870)		13,050.00
TOTAL	**$22,575.00**	**$27,413.00**

*Table 2:*Contributions to Eastern Edge Robotics.

CONTRIBUTORS	VALUE ($CAD)
Faculty of Engineering, Memorial University	10,000.00
Marine Institute	5000.00
Department of Science, Memorial University	3000.00
Summer Robotics Camps	3413.00
Individual contributions (12 people @ $500.00 each)	6,000.00
Donated materials	22,575.00
TOTAL	**$49,988.00**

2. DESIGN RATIONALE

2.1 Structural Frame

The main structural components of Chimaera are two vertical H-framed skids, two buoyancy pontoons, and a Lexan™ polycarbonate sheet covering the top (*Figure 2*). These components were all designed using SolidWorks™ 3-D CAD to allow for sufficient buoyancy spacing for all the required tools (*Figure 3*). The pontoons were milled from styrofoam using a Computer Numerical Control (CNC) router. The team then laid up three layers of fiberglass around the styrofoam until it was uniform and structurally sound. This was performed in a boat-building workshop at the Marine Institute specifically designed to allow fiberglass work without exposure to fumes to ensure safety of team members. A vertical thruster is located in a 10.16cm (4") ABS tube in the center of each of these pontoons.

The H-frames were machined from 0.953cm (3/8") Lexan™ polycarbonate. The H-frame design was chosen because a large portion of its cross section is located far away from the neutral axis, thus providing large values of moment of inertia (I) and elastic section modulus (S). Since the maximum stress (σ_m) is inversely proportional to S, it is practical for these beams to be designed with a large S value according to the following relationship:

$$\sigma_m = \frac{M}{S}$$

Where: σ_m = maximum stress
M = first moment of the cross section about the neutral axis
S = elastic section modulus

The H-Frame allows the chassis to be structurally sound, relatively light, and hydrodynamic. Two horizontally mounted thrusters are attached to the outside of each H-frame as well as the buoyancy pontoons on either side and joined transversely by a 0.477cm (3/16") Lexan™ sheet on top. This sheet supports the ROV transversely and is attached to the top of each buoyancy pontoon and H-frame. It also creates a strong platform on which multiple tools and equipment can be attached. The holes over the vertical thrusters were milled in the shape of honeycombs, which both protects the thrusters and allows for a more laminar flow of water.

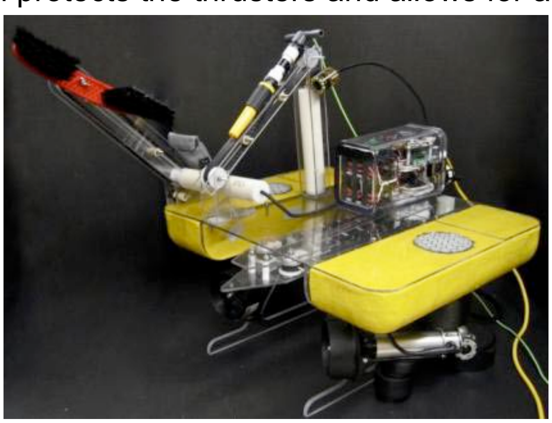


Figure 2. ROV Chimaera.

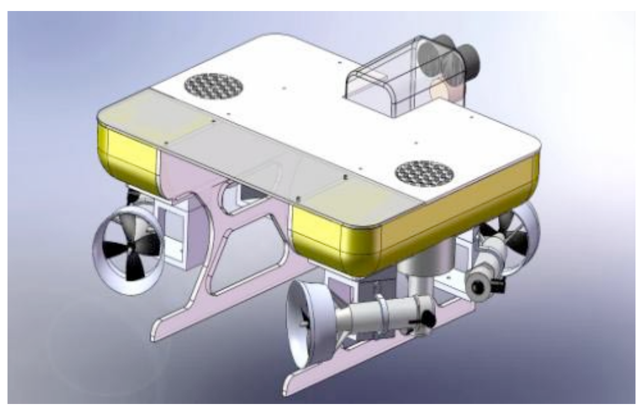


Figure 3. Solidworks diagram of Chimaera.

2.2 Propulsion

Chimaera is driven by six 90 W Inuktun™ thrusters, each with a depth rating of 300m (*Figure 4*). The thrusters have standard EO connectors and are liquid filled with Enviro-Rite™ fluid for pressure compensation. Due to wear of brushes in the original motors, new compatible

Maxon™ motors were purchased this year. These motors operate at 48V and 90W. As these motors were ordered from Maxon™ directly, they had to be modified to fit the Inuktun™ thruster mountings.

First, the thrusters were disassembled and the motors removed. Four holes were drilled around the circumference of the motor shaft end and tapped for #6 bolts, which secured the motor to the thruster shaft end frame. A hole was also drilled through the motor shaft to allow it to be keyed to the shaft of the thruster. Before reassembling, all the bearings and O-rings for each of the thrusters were inspected and lubricated appropriately. The motor wires were soldered back to the thruster connector and the thrusters were then pressure compensated with Enviro-Rite™.

Figure 4. Inuktun™ thruster.

2.3 Camera

Figure 5. PCB camera.

Chimaera uses three high-quality (400 TVL), low-light (1.0 Lux) Crystal Cam cameras *(Figure 5)*. They are 0.635cm (1/4") color CCD cameras donated by Inuktun. The cameras have a 3.6mm lens providing a 41° horizontal field of view. The cameras incorporate 12 high intensity LEDs for light. They are rated for use in up to 300m depth. A mounting bracket designed by the team provides tilt control for the cameras.The three cameras are positioned as follows: one aft facing forward and down, one aft facing forward and up, and one side-facing mounted on the starboard skid.

2.4 Tether

A custom tether designed by the team was donated by Leoni Elocab Inc. of Kitchener, Ontario, Canada. The outer portion of the tether has a low drag polyurethane coating, designed to make the tether neutrally buoyant in fresh water. The tether has two 16-gauge copper wires to transmit DC power, and two multi-mode fiber optic strands for control and video signal transmission. One of the fibre optic strands is redundant and will only be used if the other is damaged.

3. CONTROL SYSTEM

Chimaera has a control system that was programmed using the C# language. The program is run on a notebook PC and uses DirectX to read user inputs and to provide drawing capabilities. The inputs from the joystick and mouse are monitored and appropriate output responses are calculated. The C# control system was designed as a multi-threaded program (i.e. using integrated segments), which can sample data continuously. The programming flow chart shows the logic behind the control system (*Figure C1, Appendix C*).

The threads in the program are:

- Analog/Digital Converter signal processing thread, for all sensors and power supply monitoring.
- Joystick monitoring, to take in joystick information and update the thrusters and control system appropriately.

- Thruster control, to send updated values to the thruster and motors.
- Accelerometer thread, which reads and displays values for pitch, roll, and heading, as well as temperature within the submarine electronics can.
- Graphical User Interface (GUI) thread, which updates the visual representation of the ROV, both on the computer screen and the video display.
- Collections thread, responsible for taking updated values from other threads and bringing them into the ROV software.
- Report thread, which keeps detailed information on the status of the ROV and records the values for post-mission debriefing and review.
- Pressure sensor thread, which reads and displays values for external temperature and pressure, both of which are used to calculate depth.

Thread design increases processing speed by utilizing multi-core or multiple processors and allowing multiple threads to run simultaneously. Resources need to be allocated carefully, as multiple threads trying to access the same resource or variable at the same time could corrupt the information. Therefore, each physical device is dedicated to a single thread, and there is no overlap in resources.

3.1 Software Engineering

The control software has a modular design based on Object-Oriented Programming (OOP) techniques. This approach allows for changes in the program's devices or settings by changing a single line of code. It also facilitates the development of a library of classes that can be used with any ROV that follows this design pattern. For example, to update the software for a new ROV, one would have to write a new subclass for the ROV class, the MotorController class, and the ROVSystem class. New to the library this year is a SerialMotor class, which is the software domain for our PIC controlled tooling motors.

3.2 Graphical User Interface

The GUI is based on a windowed concept. The benefit of this design is that the information displayed to the pilot is sectioned into manageable windows that can be opened or closed when needed. They can also be resized and arranged according to the pilot’s preference.

3.2.1 Pre-Dive Checklist

Before the Control Panel is accessible to the user, the Pre-Dive Checklist must be completed (*Figure 6*). This ensures that all safety and runtime checks are finished before launching the ROV. Several of the checks have been automated, such as the testing of thruster control; this is displayed to the user in a window box. The remaining items on the checklist are then read aloud by the pilot before the ROV is launched to confirm that all safety issues are addressed. The checklist also has a command line parameter override, which allows the checklist to be disabled for debugging purposes.

3.2.2 Control Panel

Once the pre-dive checklist has been completed successfully, the control software is launched, displaying the main control panel (*Figure 7*). From the control panel the pilot can bring up any of the other windows; these include navigation, power control, voltage and current readings, and the video feeds from the ROV.

In addition, a GUI configuration tab can be displayed from the control panel; this allows for manual setting of the serial port assignments and individual scaling of the thruster power on the ROV. This is an important tool for the accommodation of power differences in the thrusters that may occur with use.

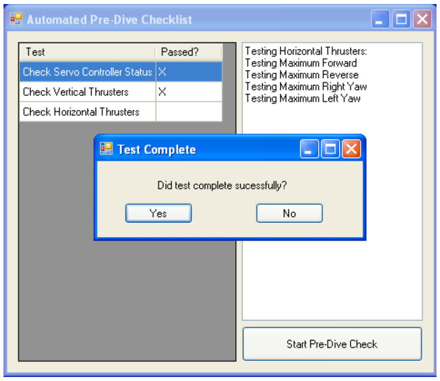


Figure 6. Pre-Dive Checklist.

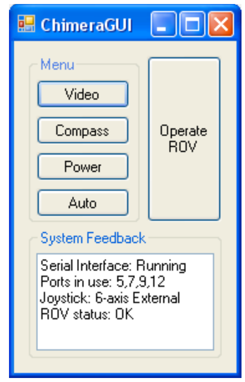


Figure 7. Control Panel.

3.2.3 Navigation Window

The navigation window displays the ROV's heading as well as the false horizon to the pilot (*Figure 8*). Integrated into the compass is a turn counter that reads the number and direction of turns that have been made by the ROV. This information helps the pilot prevent excessive twisting of the tether.

3.2.4 Power Control

In order to provide more accurate control for intricate tasks, a power gauge has been implemented. Using pulse width modulators, the power to all thrusters can be adjusted as a percentage from the GUI (*Figure 9*). Each thruster can also be scaled individually to accommodate small variations in thrust.

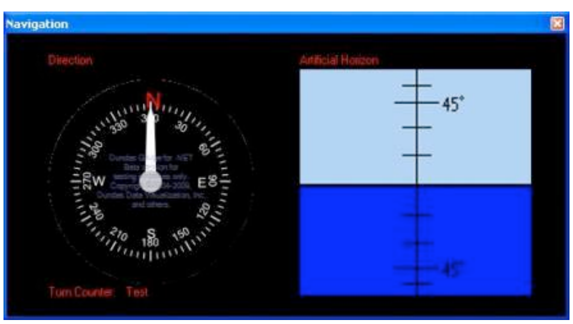


Figure 8. Navigation Window.

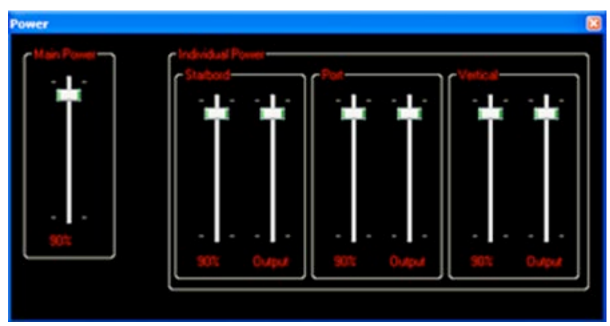


Figure 9. Power Control.

3.2.5 Voltage and Current

Voltage and current readings of the ROV are displayed to the user in this window (*Figure 10*). The readings are sent from voltage sensors in the submarine electronics can and current sensors in the topsides unit.

3.2.6 Video Feed

The video feeds from *Chimaera* are sent directly to the control software on a notebook computer (*Figure 11*). This is in contrast to previous years, when the video feeds were displayed on a standard TV video screen via RCA cables. The new setup allows further customization by the pilot in the form of window overlays and resizing.

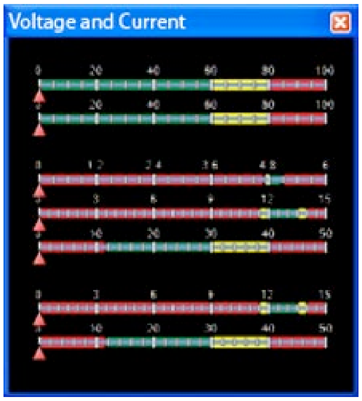


Figure 10. Voltage and Current window.

Figure 11. Video Feed.

3.3 Motor Programming

Chimaera has four motorized payload tools for the completion of tasks 2 and 3. The motors that drive these tools are controlled by a PIC microcontroller programmed via assembly language. Software is stored on the built-in EEPROM. Each PIC motor controller has its own address (0-14) stored in its EEPROM so that it stays resident when power is removed. All the PICs receive the same serial signal, but each responds only if the address corresponds with its own.The serial input consists of a 1-byte command word that can be broken down into three pieces: device address (4 bits), direction (1 bit), and speed (3 bits). Serial input is monitored to properly adjust motor speed and direction. Each PIC uses two digital output pins: one for the pulse-width signal and the other for directional control. The program uses clock interrupts to correctly output the required pulse-width signal for speed control (*Figure C2)*.

4. ELECTRONICS

The electronics system is divided into two components: the topside control unit (*Figure 12*) and the submarine electronics can (*Figure 13*). Refer to Appendix B for Electrical Schematics of the topsides control unit and submarine electronics can.

Figure 12. Topsides control unit.

*Figure 13.*Submarine electronics can.

4.1 Topside Control Unit

The topside control unit provides power distribution, monitoring, protection, interface to the PC through USB ports, video overlay, and communication with the ROV. From the main power input, power is routed through a 25A circuit breaker to the ROV at 48V and via switch-mode power supplies to the topside control electronics at 12V and 5V. Voltage, current, and internal temperature of the control unit are monitored and displayed using a Phidgets™ 8/8/8 interface with 8 channels of 0-5V A/D conversion. Control of the ROV is handled through the USB ports of a PC. One USB port is used to connect a joystick to the PC, and a second port is used for the remaining electronics controls. The electronic control USB signal is directed to a Quatech Technologies™ 8-port RS-232/422/485 device. Each port on this device is configurable as either RS-232, 422, or 485. *Chimaera* is configured with six RS-232 and two RS-485 control channels. One RS-232 line is used to control a video overlay board to display real-time information such as depth and heading on the display monitor. Four RS-232 channels and two RS-485 channels are interfaced to the ROV through the console unit of a Model 907 video/data multiplexer from Focal Technologies™. This unit allows for communication of the three video channels over a single fiber strand.

4.2 Submarine Electronics Can

The onboard electronics are located in a waterproof polycarbonate can purchased from Prevco™, with a 75m depth rating and dimensions of 9.35cm x 12.06cm x 19.99cm. The can is located at the aft end of the ROV and is connected to the tether using a brass penetrator custom-machined by the team. The onboard electronics are connected to external equipment such as thrusters, cameras, tools and sensors by two multiple-plug segmented bulkhead connectors from SeaCon-Brantner™.

The submarine electronics component consists of several units. The remote unit of the Model 907 video/data multiplexer conveys optical signals through the tether and converts them to video and data electronic signals. RS-232 signals are received from the topsides electronics by a Pololu™ 8-channel servo controller. This allows each thruster to have independent proportional control by activating six individual IFI Robotics Victor™ HV pulse width modulators.

Chimaera has several onboard analog sensors, which allow monitoring of conditions inside the can. Voltage is monitored by an 11-channel A/D converter from B&B Electronics™. The converter is connected by an RS-232 bus and has 12-bit resolution over a 0-5V range. Internal temperature of the can is monitored to ensure that components inside the can are not overheating. Temperature is measured by a Microchip™ TC1047A sensor that can record temperatures from -40 to +125°C. Relative humidity is monitored inside the can to inform the operator of condensation buildup or water leakage; it is measured using a Humiriel™ HTM1735 sensor, which will record humidity from 10-95% rH. Another sensor inside the can is an OS-1000 digital compass from Ocean Server™, which communicates over an RS-232 bus. It provides the ROV with a heading that is relative to magnetic north, which is translated to a feedback signal for auto-heading. Pitch and roll are measured by an integrated two-axis accelerometer and displayed on the topside computer monitor as an artificial horizon function. The accelerometer also provides an additional temperature sensor in the electronics can.

The ROV uses a Preciseline™ pressure transducer from Keller America™ to determine water depth. It is located onboard the ROV outside the electronics can and communicates with the topside computer over an RS-485 bus. The transducer has a floating isolated piezo-resistive sensor, which gives ± 0.1% depth accuracy, and 16-bit internal digital error correction. The transducer can measure water depths up to 20m, as it is referenced to a vacuum and configured with a full range of 300kPa. This device is used to provide feedback to an auto-depth function featured in the control system. The pressure transducer also provides a measurement of external water temperature.

5. PAYLOAD TOOLS

5.1 Tool Motors

5.1.1 Motor Encapsulation

The four payload tools for tasks 2 and 3 are all driven by 3.6V electric screwdriver motors. These motors have a planetary gear system supplying adequate torque for all the tools needed; each motor was removed from its casing and then modified to drive its respective tool. The shaft end, which previously accommodated a removable hex-bit, was tapped to allow a 0.794cm (5/16") threaded rod for attachment. These rods were machined from scrap brass and each has a 2.54cm (1") section that was polished to allow for two 0.9525cm x 1.429cm (3/8" x 9/16") O-rings in the caps to provide a watertight seal. The ends of the brass rods were either threaded or drilled for a key to drive the respective tools.

The encapsulation of these motors includes a 3.175cm (1.25") Polyvinyl chloride (PVC) tubing and two 2.54cm (1") High Density Polyethylene (HDPE) caps, with a variety of O-rings for seals. Six PVC pipes were cut to a length allowing sufficient space for caps, motor, microcontroller, and wires. The tubes were bored true at each end and then threaded to 14 threads per inch to support the cap threads. The caps were machined from 2.54cm (1") HDPE and make an O-ring seal with the face of the PVC tubing. Holes were drilled in the center of each cap. On the shaft end, two O-ring slots were bored to allow for 0.0508cm (0.020") compression on the diameter of the O-rings. All O-rings were greased with silicon grease and the caps that accommodated the electrical connection were potted with epoxy to achieve a watertight seal.

5.1.2 Embedded Motor Controllers

"Smart" motor controllers were constructed to drive the tool motors (*Figure 14*). The team decided to custom-design controller boards and DC motors to replace servos, which we have had trouble waterproofing in the past. The goal was to develop an integrated controller that would allow the control software to address individual motors. Also, rather than having to reprogram each PIC individually, each address could be reassigned during operations. To this end, we developed a controller around the PIC18F1320. The controller accepts a serial signal with an 8-bit control word. The PIC's firmware accepts and processes the serial stream comprised of these control words. If the upper nibble of the control word matches the internal address stored in the chip's EEPROM, the device sets the tool speed and direction based on the value of the lower nibble. The single direction bit controls the position of a double pole double throw relay which enables the controller to pass the current forward or backwards depending on the motor direction desired. The 3-bit speed portion of the control word drives a routine in the PIC's firmware, which drives a pulse width modulated signal with a variable duty cycle. This effectively delivers 0-5V DC to the motor coils that in turn controls the speed at which the motor rotates. The controller address can also be reassigned without reprogramming. If the high nibble of the control word equals 1111 binary, then the controller loads the lower nibble of the control word into its EEPROM as its new internal address. This protocol allows 15 tools to be controlled from one serial data stream. A schematic of the motor controller is provided in Appendix B (*Figure B3*).

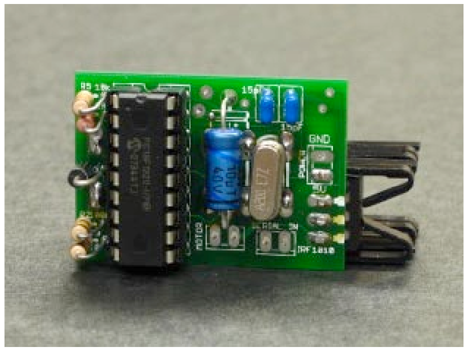


Figure 14. Embedded motor controller.

5.2 Task 1: Survey and inspect the submarine for damage

To survey and inspect the submarine for damage, *Chimaera* incorporates a side-facing camera mounted on the starboard skid (see section 2.3). This positioning allows the pilot to drive in a relatively straight path around the submarine while locating the sites of damage. Alternatively, we considered using a forward-facing camera and swaying the ROV around the submarine tower. The side-facing design was chosen because it was found to be a faster and more accurate method for completing the task.

5.3 Task 2: Pod posting

For the task of opening the ELSS hatch, one tool has been designed that will also complete the RORV mating in task 4 (*Figure 15*). This tool consists of a 11.4cm (4.5") ABS pipe connector, two Lexan™ guides and four Lexan™ legs. In order to open the ELSS hatch, the ROV will be positioned so that the legs engage in the cavities of the hatch handle as the legs are naturally in their down position due to gravity. The bottom of each leg is curved in order to hook the hatch handle. Once engaged, an encapsulated screwdriver motor rotates the tool in order to achieve a 360-degree turn and free the hatch. With the hooks still engaged, *Chimaera* is able to open the hatch by driving vertically upwards. Once the ELSS pods have been delivered, the hatch is closed by re-engaging the tool legs with the arms of the hatch and driving the motor in the opposite direction.

For the task of retrieving the collection of ELSS pods, a specially designed single-function tool was manufactured. The tool has been named *Pleopods*, due to its resemblance to the swimmerets of a lobster (*Figure 16*). It is capable of collecting and securing all five ELSS pods from the carousal, and transporting them to the submarine emergency hatch, at once. The dimensions (W x H x L) of the *Pleopods* is approximately 15.2cm x 5.0 cm x 38.1cm (6" x 2" x 15"). Capture of the ELSS pods is accomplished by two timing belts running in parallel, both studded with nylon screws. A single motor drives a gear system that in turn drives both of the timing belts, which rotate in opposite directions.

Once the ROV is positioned in front of the ELSS carousal with the forward end of the tool near the U-bolts of the ELSS pods, the motor is activated in the forward direction. This moves each of the nylon screws backwards on the outboard side of the tool. As the nylon screws traverse the forward idler gear, they engage the U-bolts and channel them between the outer rails and timing belt. Once all five ELSS pods are secured in the channel, the ROV can rise and transport them. Since the nylon screws are slightly flexible, rails on either side of *Pleopods* support the weight of the ELSS pods. Finally, during dispensing, the ROV will secure itself along the railing of the submarine hatch, and *Pleopods'* motor is reversed. By reversing the direction of the timing belts, the ELSS pods are released from the channel and the nylon screws at the front end, two at a time. Tensioning of the timing belts was accomplished by a linear displacement threaded mechanism. To reduce the size of the tool, the two timing belts were installed such that they pass through the ELSS carousel length-wise.

The rationale behind this design is to allow the ROV to engage in retrieving the ELSS pods while only considering three degrees of freedom: surge, sway, and yaw. Because the ROV is situated at the bottom of the pool during retrieval, the other three degrees of freedom - roll, pitch, and heave - are constrained. Aside from the nylon screws and timing belts, all of the components were manufactured using the CNC machine in-house by the team. The body is made of Lexan™, while the gears are constructed from HDPE.

An alternative design for completing this task that was considered was a pneumatically-operated grabber with finger-like appendages. Compressed air travels down from the topside to a manifold where different pressure differentials activate corresponding pneumatic plungers; these plungers engage each of the ELSS pods by the U-bolt. The benefit to this design was its simplicity, however several drawbacks led to the use of *Pleopods* instead. One is the pneumatic hose that would be required to accompany the tether for supplying air to actuate the plungers. More importantly, this tool required the pilot to conduct the retrieval and delivery of the ELSS pods with all six degrees of freedom, increasing the difficulty of the task and the time required for completion. Also, the delivery of the ELSS pods into the submarine emergency supply hatch would require intricate maneuvers over the opening while repositioning each of the retrieved ELSS pods for release.

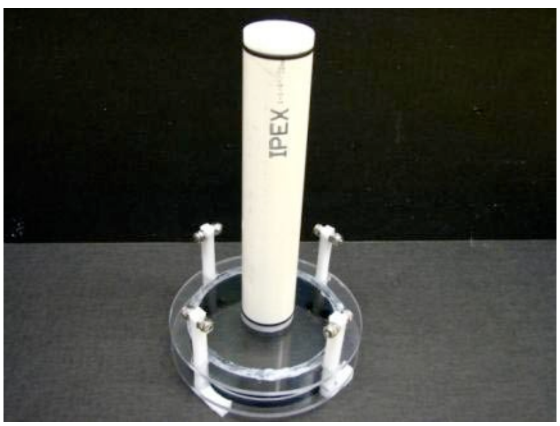


Figure 15. ELSS hatch opening and RORV mating tool.

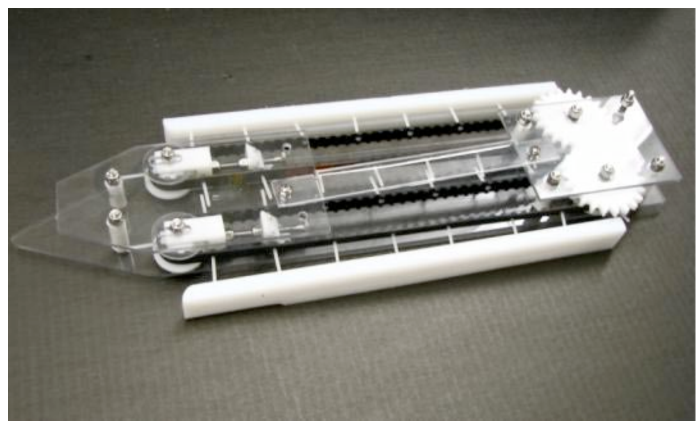


Figure 16. Pleopods ELSS retrieval tool.

5.4 Task 3: Ventilation

This task required that the ROV insert an airline into the inlet valve connection, which is at a 45 degree angle with the horizontal plane. To accomplish this mission, the team designed a motor driven timing belt that is magnetically coupled to the airline (*Figure 17*). This is achieved by securing a temporary magnetic strap to the airline; the timing belt on the tool has super strong rare earth magnets attached at intervals. The entire assembly is supported by a Lexan™ structure that extends back to the ROV, which was fabricated from a 0.477cm (3/16") sheet. The belt is driven by an electric screwdriver motor and moves either forward or backward to drop off or pick up the airline, respectively. With the stern of the ROV located on the escape hatch of the submarine (task 4), this tool will be positioned in front of the inlet valve connection. At this point the timing belt is rotated using the tool motor, inserting the airline into the inlet valve and releasing it. To retrieve the airline, the motor is driven in the opposite direction and the belt moves accordingly; the magnets engage and the airline is drawn out of the inlet valve.

An alternative design considered for this task was a dual-pronged claw. Two guides were used to help position the ROV at the inlet valve connection. An elastic cord was secured around the guides, which would loosen and release the airline upon contact of the guides with the inlet valve. An electric screwdriver motor was used to insert the airline. This design was discarded because it took too long to complete the task with the low speed of our tool motors and was not as consistent as the chosen design.

The mission specifications also require that the ROV manipulate a valve lever on the port side of the submarine conning tower. This lever penetrates the conning tower at a right angle and has two positions, forward 90 degrees and aft 90 degrees. The tool designed for this purpose employs a rotary brush that is belt-driven by an encapsulated screwdriver motor; this is mounted on the upper chassis plate of the ROV (*Figure 18*). Attached to the motor is a drive shaft that fits into a driving gear via a key-slot. The tool employs a 3.81cm (1.5") drive gear, 3.81cm (1.5") spool and a 35.56cm x 1.905cm (14" x 0.75") timing belt, encased by 0.477cm (3/16") Lexan™ for its structural frame. The belt tension is maintained by hard mounting the driving gear and idler wheel at its furthest possible position. The belt is oriented approximately 45 degrees from the horizontal plane of the ROV, which allows access to the valve in any position on the conning tower.

A 25.4cm (10”) long brush is attached to a pinned spool at the apex of the tool. The motor directly engages the driving gear towards the base of the tool. This allows the belt to rotate about the gear and spool, which in turn rotates the brush tool. The brush bristles provide sufficient strength with inherent flexibility to bypass obstructions while it rotates about the lever. Driving the motor in the forward position allows the brush to spin clockwise, orienting the valve level to the open position. To close the valve, the motor is driven in reverse; this causes the brush to spin counter-clockwise, returning the valve to its original closed position.

A tool that used linear forward motion was also considered for this task. This would involve an oval-shaped Lexan™ plate with the ability to pivot on one side; a hill-shaped track would be cut out of the plate. When the track engaged the valve and the tool moved forward linearly, the valve would follow the line of the track and open; it could be closed by reversing the ROV. This tool was discarded in favor of our current one because it did not work consistently.

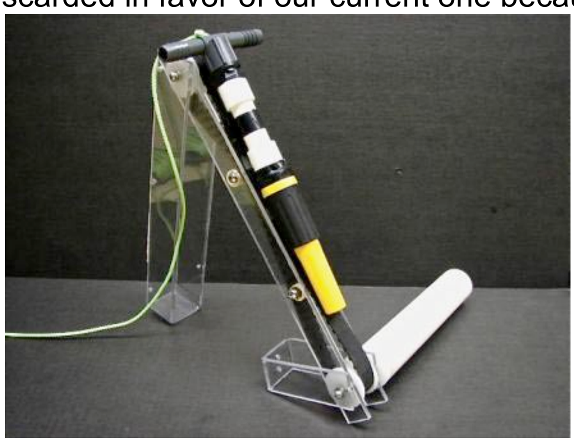


Figure 17. Airline delivery tool.

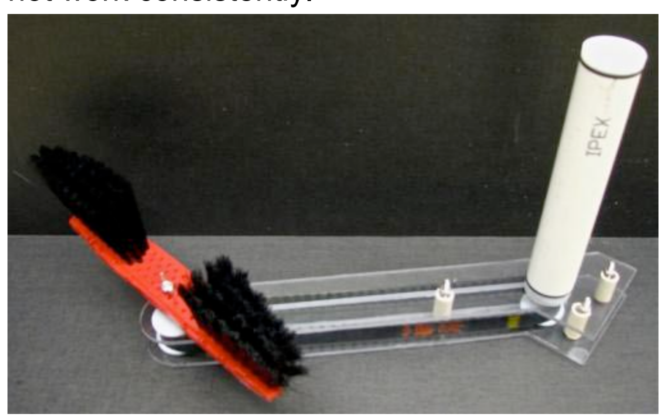


Figure 18. Valve manipulating tool.

5.5 Task 4: RORV Mating

The same tool used to open the ELSS hatch and allow pod posting in task 2 is utilized for RORV mating to the submarine escape hatch as well (*Figure 15*).The ROV first situates on the crate directly in front of the conning tower. In this position, the ABS pipe is located directly over the RORV hatch. The floating Lexan™ legs will rise as the ABS pipe is lowered onto the escape hatch in order to seal the hatch for the required 20 seconds.

Alternatively, the team considered placing the ABS pipe centrally under the ROV. Using this design, no other mission tasks could be completed while mated to the submarine. The positioning of the ABS pipe on *Chimaera* allows us to complete tasks 3 and 4 simultaneously, saving valuable time.

6. CHALLENGES

Although all team members are attending post-secondary institutions, we are involved in many different programs and are at different stages in our education. While some of us are in school, others are on work terms, and most of us balance school and part-time jobs. The result is that projects get disrupted when the members working on them one week cannot attend the next meeting, and other members are unsure of the progress that has been made. This presents a major logistic challenge – organizing such a large team and maintaining the flow of our project. To aid in this task, we started using an open-source application called Dropbox^{TM} (http://www.getdropbox.com) which allows synchronization and version control of important electronic files. These include SolidWorks^{TM} drawings, software source code, and schematics that all team members can access remotely from any computer. We have found that this helps enormously in keeping everyone informed of the team's progress if they are away on a work term or miss a meeting, and as a consequence we waste less time in catching up.

Another challenge we faced was fabricating our own embedded motor controllers for the payload tools. We encountered several problems during this process, such as running the circuit with an H-Bridge at an operating voltage of 12-50V while the motors were designed to run at 3.6V. This is further discussed in Troubleshooting Techniques.

7. TROUBLESHOOTING TECHNIQUES

A major challenge that required troubleshooting this year involved making embedded motor controllers for use with various tools on *Chimaera*. We are using PIC controllers to generate a pulse width signal. The control word is sent over an RS-232 connection to the PIC controllers, each of which has a unique identifier. This signal is then transmitted to an H-Bridge. The H-Bridge generates the same pulse width signal while tolerating a higher current draw, which is necessary for providing power to the motors for each of the tools. The PIC controller, H-bridge and all associated components are encased in the motor's housing.

Once fabrication was complete and testing began, we immediately found a problem. The system worked for a few seconds, but then the motor invariably starting running at full speed and we lost control. The team had a brainstorming session and constructed a list of possible problems, prioritizing in order of likelihood and simplicity. We then used a trial and error approach to determine the difficulty. First, we eliminated the PIC controller from the circuit and controlled the H-Bridge using a function generator. The fact that the system worked under these conditions told us that the problem was not with the H-Bridge or motor.

Our suspicion was that feedback from the motor was interfering with the PIC's output signal. Our next move was to connect the H-Bridge and the PIC controller to the power supply, while still controlling the H-Bridge with the function generator (instead of the PIC's output). We hoped to determine if the noise was caused by the shared power supply. When connected to the 5V power supply controlling the PIC, the H-Bridge and motor stopped working. We monitored the voltage and current through the H-Bridge and found that it's power limits were not exceeded.

Although the H-Bridge's operating voltage was specified as 12-50V, our motors were only rated at 3.6V. We determined that there were two possibilities – either run the circuit at a voltage well below that specified for the H-Bridge, or run at the higher voltage and find a way to decrease the current before it reached the motors. We first tried running the circuit from a 5V supply. When the H-Bridge did not function, we moved back to the 12V supply and, to decrease current to the motors, added two ceramic resistors in series with the H-Bridge. This helped dissipate excess power to the motors, and the speed control worked but the resistors generated an inordinate amount of heat.

Given the problems experienced with the H-Bridge, we decided to use a single MOSFET to handle the power across the motors and loop the current through a double pole double throw relay. Using this method, the motor ran off the 5V supply and we were able to control both speed and direction from the PIC, but only intermittently. We observed that when driving the motor at high speed and then changing directions, we lost control. We suspected that this was a result of the high current that ran through the system when stopping the motor. To rectify the problem we added a shunt diode, which allows current to flow away from the motors during a spike in current, such as occurs with a change in direction. This proved an effective solution and our motor controllers functioned successfully.

8. FUTURE IMPROVEMENTS

One improvement that our team has been hoping to implement for some time is to design and build our own brushless thrusters with embedded PIC controllers. These would be more reliable, efficient and durable than our current commercial thrusters. However, the new MATE competition guidelines stating that only 48V power supplies would be available prompted us to purchase new 48V motors for our six Inuktun™ thrusters, which were previously running at 24V. The cost of this and also the time involved in procuring the proper replacement parts inhibited our team from producing our own thrusters this year. We plan on completing these thrusters for next year's competition.

The benefits of the thrusters we plan to design would include:

i) Brushless motors: this would greatly reduce the amount of maintenance required. It would also produce a higher power-to-weight ratio, and would cause less electrical noise.

ii) The ability to consider different thruster arrangements: because the thrusters would be brushless, the permanent magnets and windings could be placed in different positions relative to the prop.

iii) Embedded controllers: this would allow for fewer connections from the electronics can to the thrusters and also for a smaller can, as pulse-width modulators would not be needed.

Other future improvements that our team is considering include:

i) A better tether management system, with hybrid fiber-optic rotary joints and an improved launch and recovery system.

ii) The implementation of miniature hydraulics to mimic a Shilling™-type robotic arm. This would include a seven-axis manipulator - a multi-purpose tool that could be used for multiple years and competitions.

9. LESSONS LEARNED/SKILLS GAINED

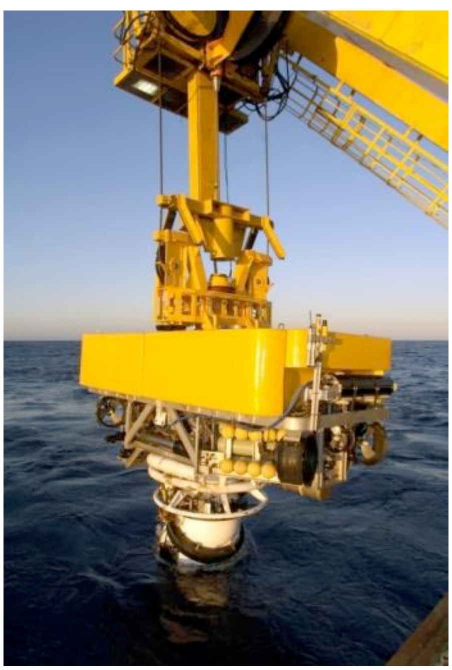
This year as always, new mission tasks in the MATE competition required our team to learn and improve upon many skills, both technical and interpersonal. Of particular technical interest this year is the use of custom-designed PCBs in our embedded motor controllers for use with our payload tools. These motor controller circuits are placed inside waterproofed motor housings. In order to make the circuit boards as small as possible, we chose to design and order our own PCBs. This is the first year that custom PCBs have been incorporated into our ROV.

Designing our PCBs required us to learn how to use the software program Eagle Layout Editor^{TM}. Once several team members became proficient in the use of this program, we used it to draw a schematic of the circuit and lay out the components on the board. We then generated Gerber files and sent them to Speedy PCB, who fabricated the boards for us. Once we received the boards, we soldered our components and placed them in waterproof tubes.

In addition, many more team members became proficient in the use of a CNC router. We began to use this tool last year with the milling of our pontoons. This year, almost all parts of our ROV were fabricated using the CNC router, including flotation, chassis, payload tools, the electronics panel of the topsides unit, and thruster mounts. Our goal has been to cut as little as possible by hand, as the CNC router allows incredible accuracy.

Interpersonal relationships are always an important aspect in the success of Eastern Edge Robotics because of our large team. This year, we have 26 team members from many different disciplines, including biochemistry, computer science, ROV technical programs, and electrical, mechanical and ocean naval engineering. Working with such a diverse group of people is both a challenge and a pleasure. While diversity is beneficial for divergent thinking during the brainstorming process, convergent thinking is required to pick ideas and this can result in disagreements. To resolve these issues, we try to be as open-minded as possible and choose multiple ideas for testing. In this way, the team can come to an agreement objectively. It can also be challenging working with people from other disciplines because of a difference in knowledge. It is important to realize that while other team members may not be proficient in your area of study, everyone has important skills to bring to the process. However, we feel that it is essential that all team members have a good understanding of all components of the ROV. To ensure that this is the case, we schedule time during our team meetings to get together and undergo tutorials in various areas by members of the team who are experts. Each year, team members learn how to work with others outside of their area, a skill that is essential in any industry position.

10. DESCRIPTION OF A SUBMARINE RESCUE SYSTEM



Remotely Operated Rescue Vehicles (RORVs) represent a huge stop forward in submarine rescue. By minimizing the number of operators required onboard, RORVs maximize the number of survivors that can be returned to the surface on each trip, saving valuable time that could be the difference between life and death. The *Remora* is the first RORV built by Ocean Works International in Vancouver, BC, Canada. It was operated by the Royal Australian Navyin support of the Royal Australian Navy Submarine Service from 1995-2006.

The *Remora* is aptly named after a slender marine fish that attaches itself to larger fish by means of a sucker on the top of its head. The rescue system operates in a similar manner, by mating to the submarine and allowing passage of survivors into the 16.5-tonne submersible. The *Remora* is capable of carrying seven people (1 attendant and 6 survivors) and includes injured personnel capability via a harness and mountain rescue hoist. It can operate at depths over 500 meters, in winds up to 3 knots, at Sea State 5 (significant wave height of 4m), and at internal pressures up to 5 bar by mating to the Transfer Under Pressure chamber. It is capable of mating to any NATO class submarine, lying at an angle up to 60 degrees from the vertical. The submersible has a rescue cycle of 3 hours; it is maintained ready to deploy within 12 hours of alert and can reach anywhere in Australia within 36 hours. It is kept in an ISO container and transported by C-130 Hercules transport aircraft.[1]

The *Remora* has six onboard cameras: one on the internal skirt, one on the internal bell, two forward, one aft, and one upper. It incorporates a 300MHz commercial sonar, an acoustic tracking system and GPS. It is powered and controlled through an armored electro-fibre optic umbilical 914m long. The unit is powered by a 440V, 3 phase, 60Hz supply and draws 496kW. There is also one Genset incorporated in suite for redundancy.[2]

The *Remora*'s Launch and Recovery System (LARS) is an A frame mounted to an H frame Deck Support Assembly. The system requires 300m^2 clear deck space aboard the mother ship. A team of three is required in the control van, including a Pilot, Navigator, and Dive Supervisor. Another compartment of the ship houses Naval Coordinator Rescue Forces who communicate with the sunken submarine via underwater telephone, with shore-based authorities via INMARSAT, and with local rescue via VHF radio. Also contained on the ship are LP and HP air compressors, bottled gases, and 12 ELSS pods. The pods are normally deployed ahead of the main rescue submersible by another ROV or Newtsuit.[3]

In December 2006, two civilian contractors were trapped in the *Remora* for 12 hours off the coast of Perth, Australia, when the cable of the submersible's winching system snapped. The RORV was left on the seabed until April of 2007, when it was retrieved and sent back to Oceanworks for an overhaul. However, the Navy still has not acquired proper certification for the system due to new safety standards that would require millions of dollars worth of modifications. They are currently investigating new submarine rescue systems for future use.[4]

As submarine safety continues to be a concern in the industry and designers look for new, more reliable rescue solutions, it becomes increasingly important that we learn from the strengths and weaknesses of previous systems. The story of the *Remora* illustrates one of the greatest challenges when producing submarine rescue systems; designing and building a system and beginning operation before newer safety standards and technology render it obsolete.

References
[1]Interview with Darryl Rundquist, Sr., Manager, ROV Operations, Oceaneering International, Inc.
[2]http://www.idpm.biz/downloads/Remora_Fact_Sheet.pdf
[3]http://www.navy.gov.au/Submarine_Rescue_Vehicle
[4]http://www.rovworld.com/phpnuke/modules.php?name=News&file=article&sid=2876&mode=thread&order=0&thold=0
Photo Credits: http://www.defence.gov.au/media/download/2006/dec/20061205b.cfm
http://www.navy.gov.au/Submarine_Rescue_Vehicle

11. REFLECTIONS ON THE EXPERIENCE

"As a first year post-secondary student, there seemed to be an overwhelming number of possibilities open to me in terms of a career. I began the Ocean Naval Engineering program at the Marine Institute but was not completely confident that I had chosen the right path. While seeking information on the ROV program offered at the MI, I heard about the MATE International ROV Competition. Joining the Eastern Edge Robotics Team and participating in the competition helped convey to me the exciting opportunities in the ROV industry and led me to change my career path towards becoming an ROV technician. I have dramatically increased my knowledge in the commercial ROV industry and have gained skills necessary to enhance my learning experience at school. Working towards the MATE competition with students from disciplines as diverse as computer science, biochemistry, and mechanical, electrical, and ocean naval engineering has shown me many different sides of the industry. It has also given me a feel for what it is like working with professionals from a number of different specialties and the importance of many points of view in solving a problem creatively. Overall, participating in the MATE International ROV Competition has been an invaluable experience, particularly in developing my mechanical design skills and creating opportunities for networking with industry professionals."

-John Hillier, 1st year student, ROV Technician Program, Marine Institute

"Aside from how much fun it has been, being a member of the Eastern Edge Robotics team has been of inestimable importance in the progression of my post-secondary career at Memorial University. When I entered university, I was particularly interested in two areas: Engineering and Biochemistry. I eventually chose the latter as the most beneficial route to my goal of becoming a physician and medical researcher. However, participating in the MATE International ROV Competition has allowed me to pursue my interests in Engineering and underwater technology apart from my degree. One of the most exciting and promising new areas of medicine is the use of robotics in surgical tools, and I hope to pursue research in this area that combines both of my academic interests. I believe that robotics has the potential to improve the accuracy and dependability of health care immensely and that the MATE competition has provided me with a solid background in this area. Because of my involvement in the competition I was awarded the Student Innovation Fund and have been featured on Memorial University's website. Also, making new friends and contacts from all over the world has been extremely rewarding."

-Cait Button, 3rd year student, Biochemistry, Memorial University

12. TEAMWORK

In order to organize our team and ensure that all parts of the process involved in the MATE Competition were completed on time, we designated each team member to a certain area. While all members were involved in every aspect of the process (design, construction, testing, and communications), this allowed us to delegate responsibility and ensure that each component would be completed on time. To aid in this goal, we completed a chart noting each member's areas of responsibility (*Figure 19*).

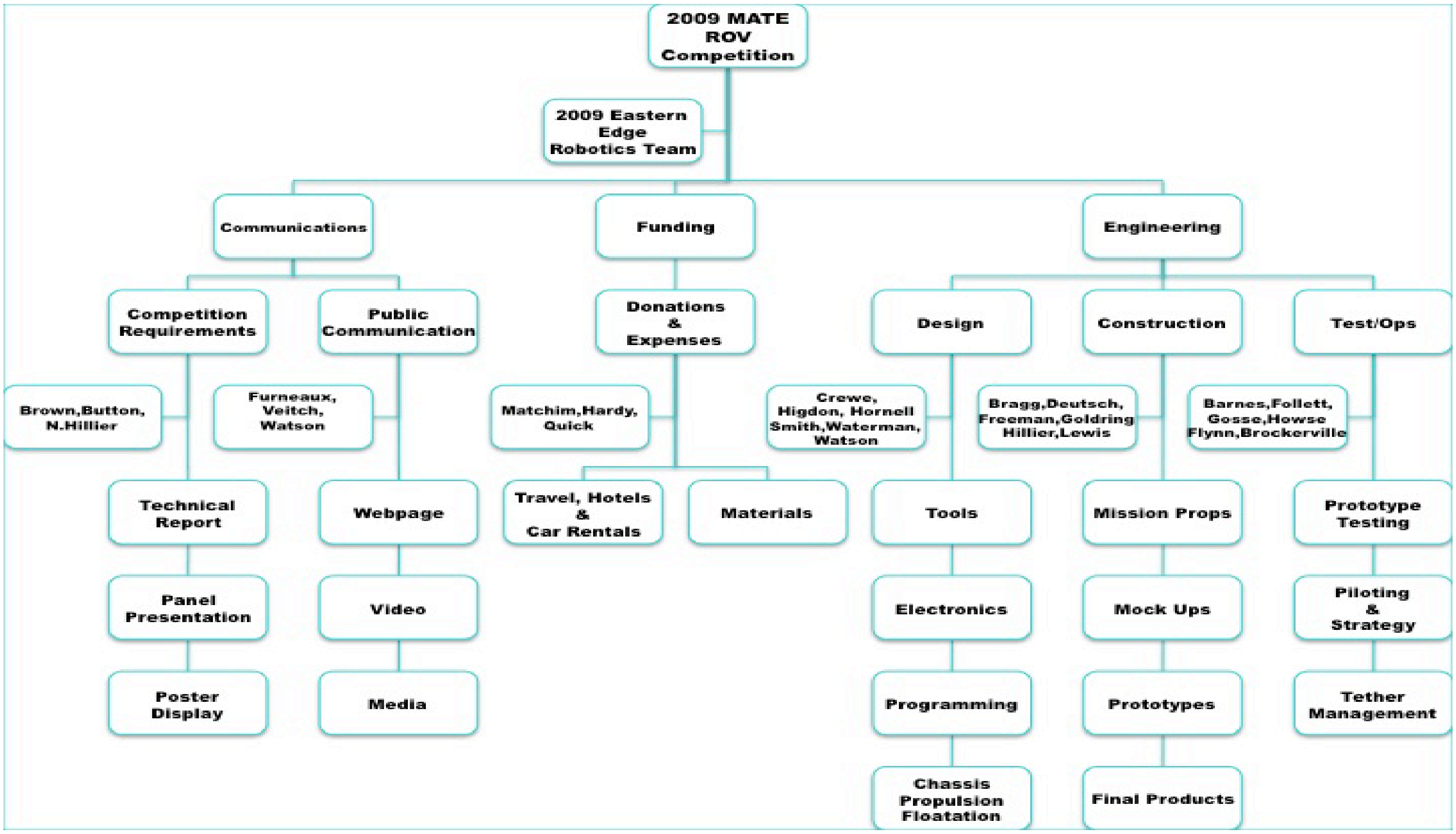


Figure 19. Team organizational chart.

13. ACKNOWLEDGEMENTS

We would like to extend our sincere gratitude to the following sponsors:

Dundas Data Visualization (gauge presentation software)
Eastern School District, NL, Canada (donation of facilities)
Imprint Specialty Promotions (donation of polo shirts)
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MATE (for providing this opportunity)
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Memorial University Department of Science (financial assistance)
Memorial University Faculty of Engineering (financial assistance)
O’Donel High School (use of facilities and equipment)
Focal Technologies (Moog) (donation of multiplexer for fiber-optics)
SubConn (donation of connectors)
Ultragraphics (donation of t-shirts)

To our parents, families and friends, for their support and encouragement;

And a very special thanks to our mentors -Clar Button, Tom Donovan, Dwight Howse - for donating so much of their time and energy to this project.

APPENDIX A - FLOW ANALYSIS

Computational Fluid Dynamic Calculations Using FloWorks

A fluid dynamic calculation was conducted using FloWorks, computational fluid dynamic software created by SolidWorks. This was done to show the drag forces exerted on the ROV as it travels through water. The motion of the ROV has been simulated as follows:

- Surge forward at 025 m/s
- Heave up at 0.25 m/s
- Heave down at 0.25 m/s

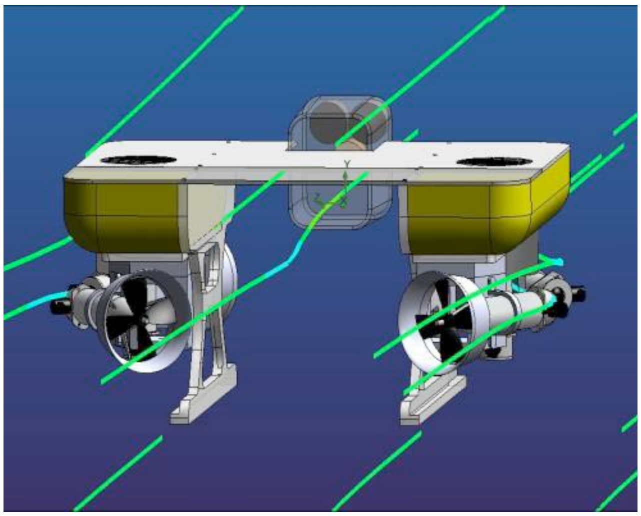

Figure A1. Flow trajectory of fluid particles as the ROV surges forward at 0.25 m/s.

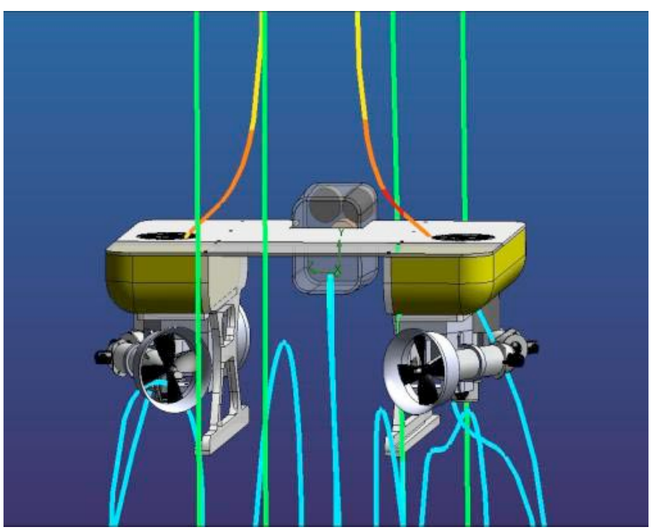

Figure A2. Flow trajectory of the fluid particles as the ROV heaves up at 0.25 m/s.

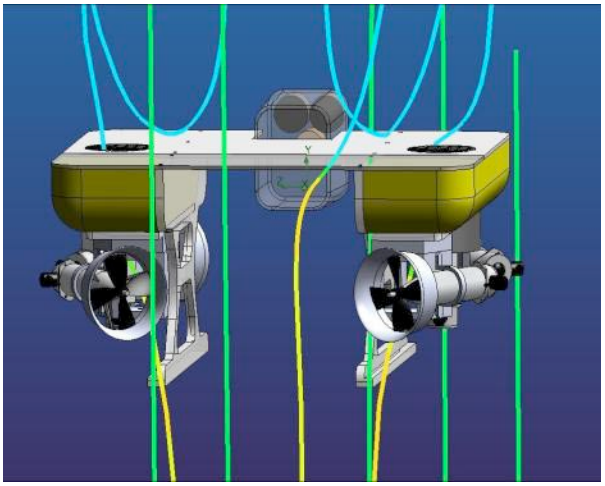

Figure A3. Flow trajectory of the fluid particles as the ROV heaves down at 0.25 m/s

The following table displays the respective forces experienced by the ROV:

Table A1: Forces on ROV in motion

Parameters		Drag Force [N]			
Motion	Velocity	Converged Value	Averaged	Min.	Max.
Surge Forward	0.25 m/s	1.775825765	1.76973688	1.7530698	1.777596896
Heave Up	0.25 m/s	-9.98181839	-9.50140447	-9.98181839	-8.872780098
Heave Down	0.25 m/s	8.378306671	7.96858792	7.48576048	8.378306671

The drag force is in the opposite direction to their respective motion, e.g. surge forward (positive X-direction) at velocity of 0.25 m/s exerts a force of 1.77 N in the negative X-direction.

Drag Coefficient Calculations:
The force on a moving object due to a fluid as defined by the drag equation is:

$$F_d = \frac{1}{2}\rho V^2 C_d A$$

Where:
F_d is the force of drag [N]
ρ is the density of the fluid [kg/m^3]
V is the velocity of the object relative to the fluid [m/s]
A is the reference area, which is the cross sectional area perpendicular to the direction of motion [m^2]
C_d is the drag coefficient [non-dimensional]

Rearranged for drag coefficient:

$$C_d = \frac{F_d}{\frac{1}{2}\rho V^2 A}$$

The density of water will be assumed to be 998.19 kg/m^3, and the reference areas to be approximated as follows:

Front:
A = Width X Height – $(\text{Width X Height})_{void}$
A = (0.630m)(0.297m) – (0.630m)(0.097m)
A = 0.126 m^2

Top:
A = Width X Length
A = (0.630m)(0.500m)
A = 0.315 m^2

Surge at 0.25 m/s:C_d= 0.450

Heave Up at 0.25 m/s:C_d = 0.967

Heave Down at 0.25 m/s:C_d = 0.811

APPENDIX B - ELECTRICAL SCHEMATICS

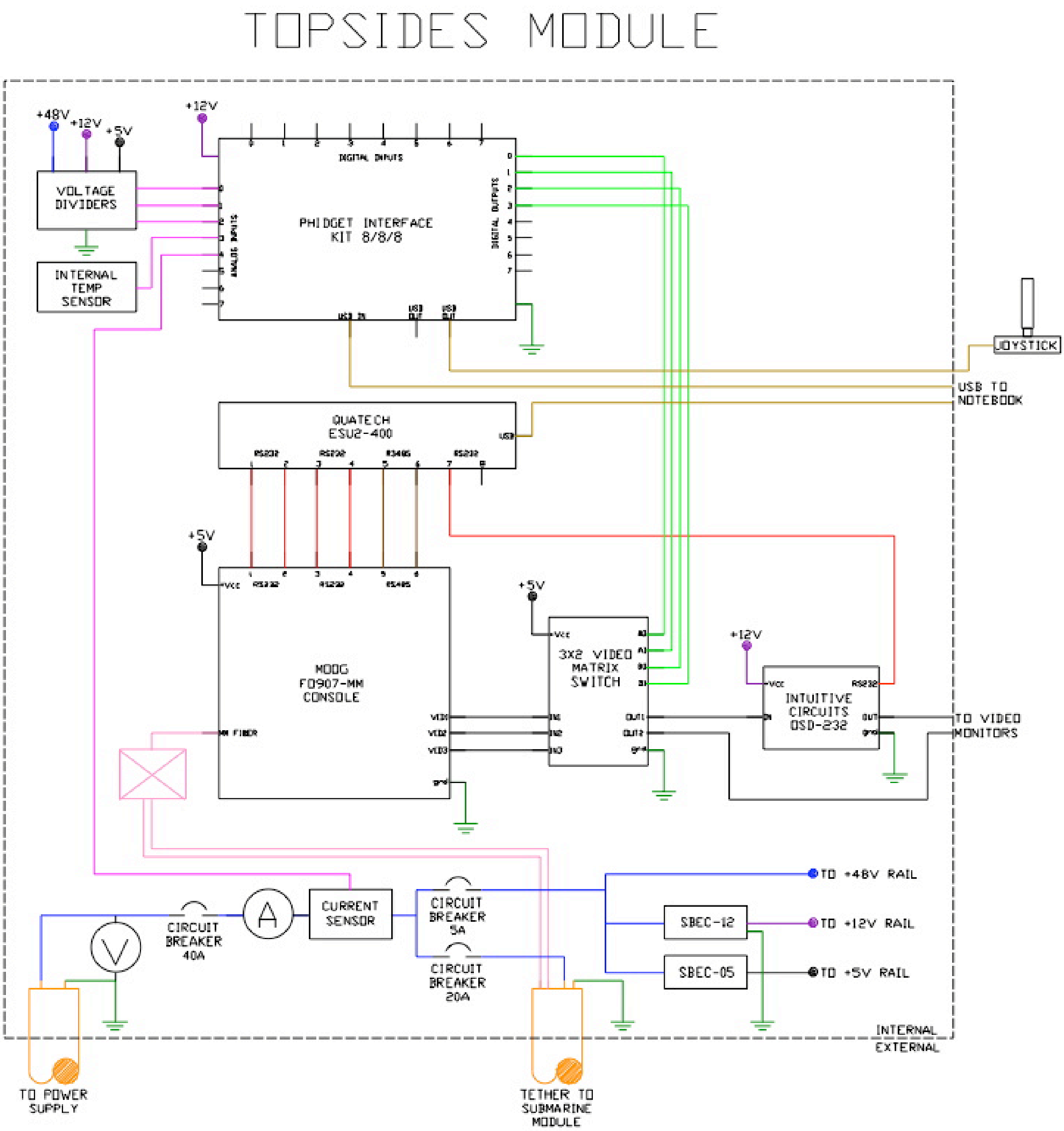

Figure B1. Schematic of topside control unit.

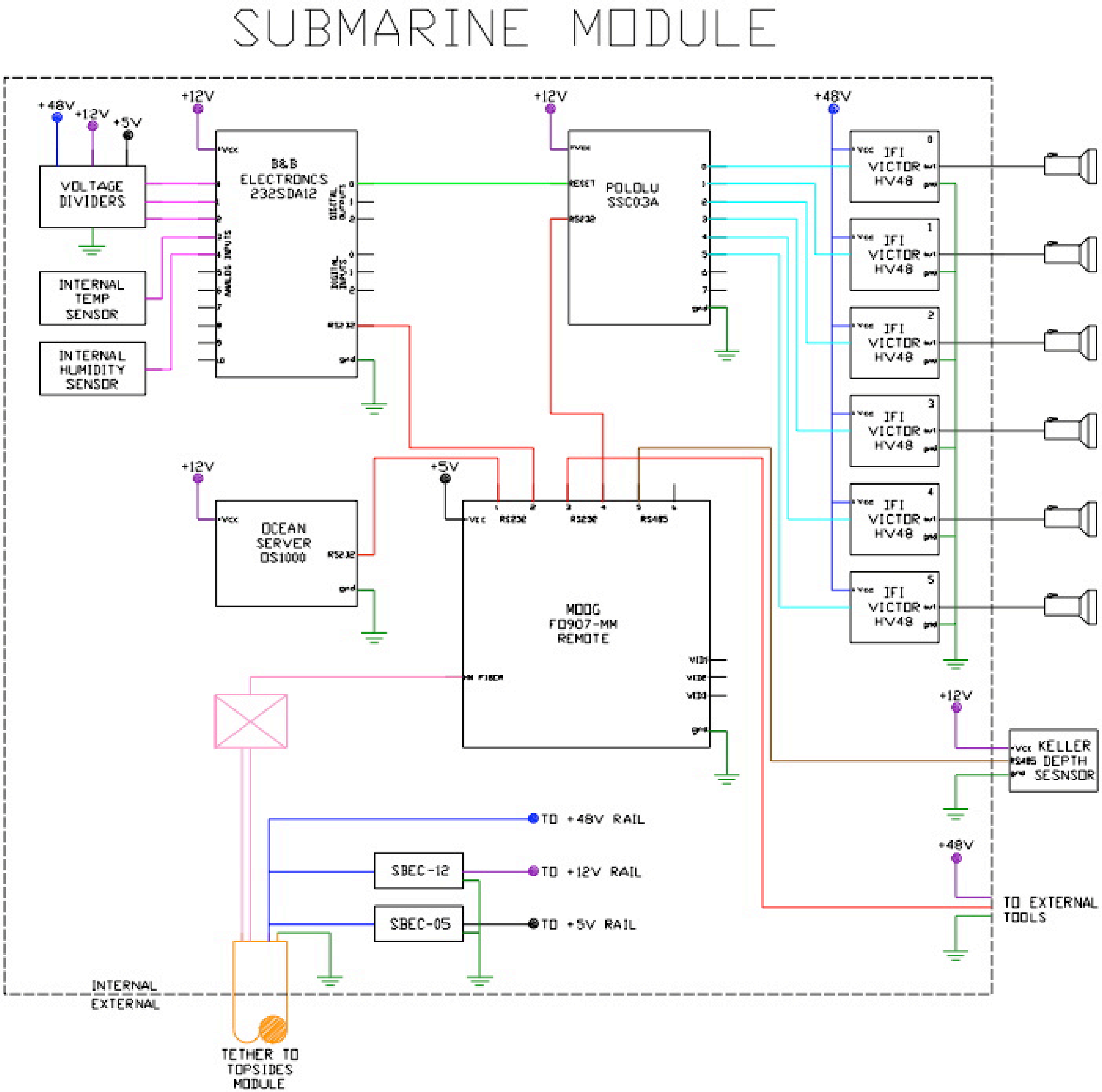

Figure B2. Schematic of submarine electronics can.

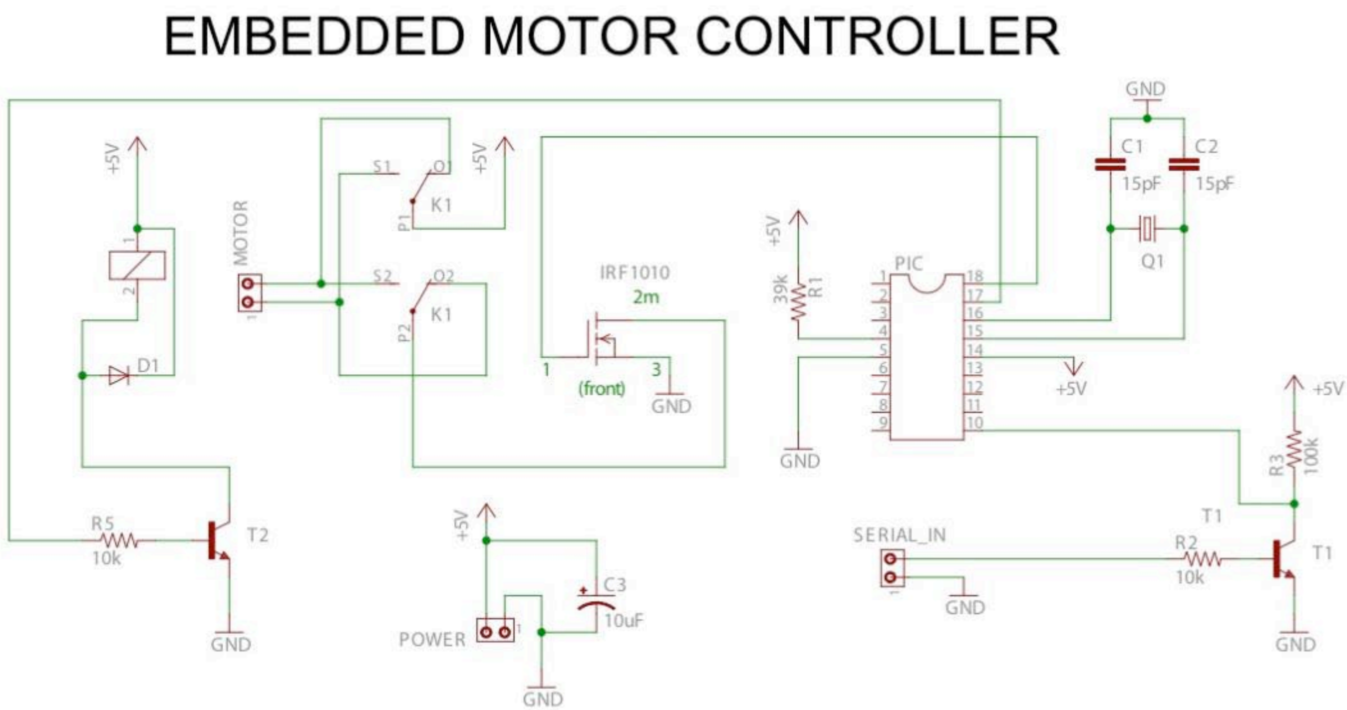

Figure B3. Schematic of embedded motor controllers.

APPENDIX C - PROGRAMMING FLOWCHARTS

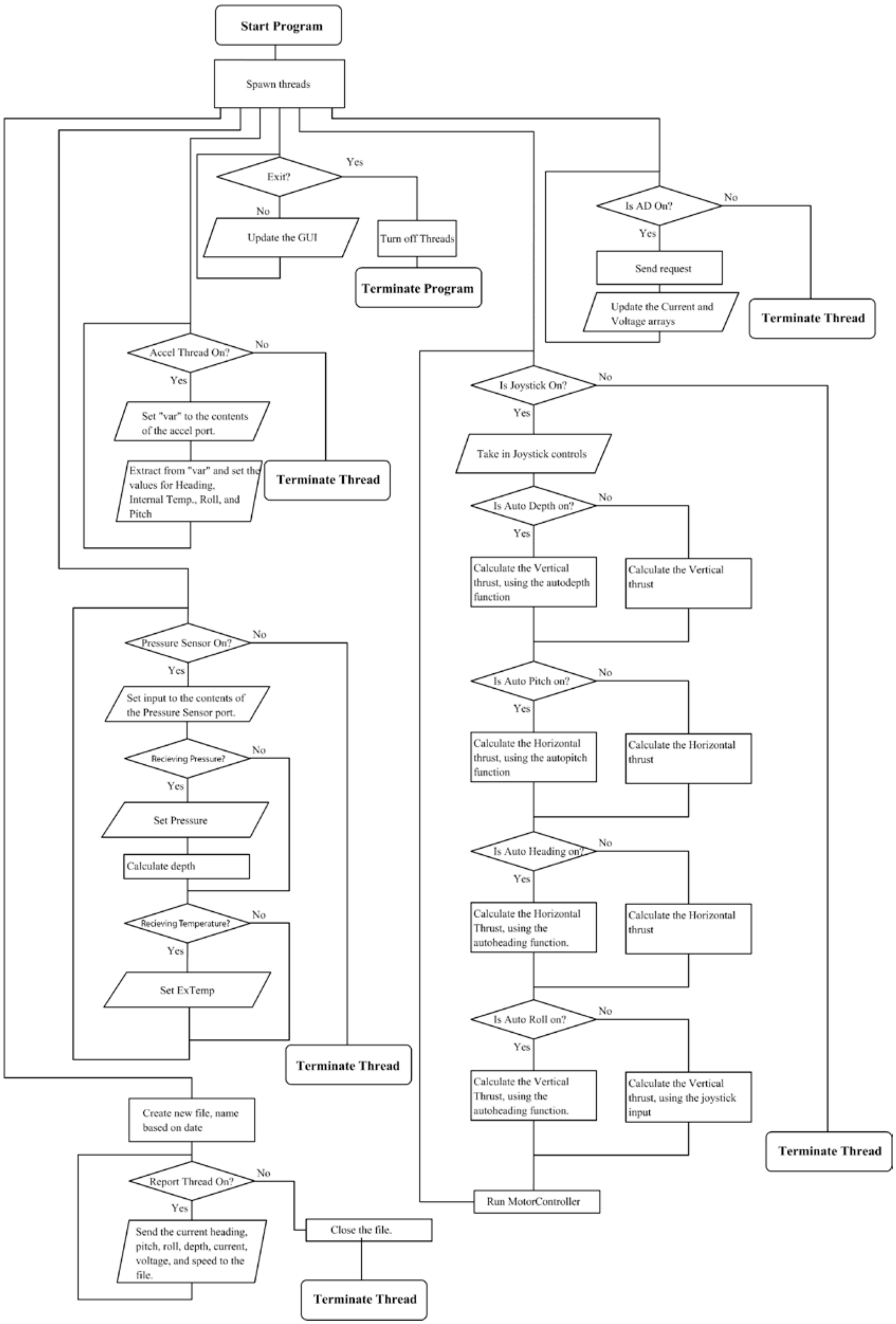

Figure C1. Programming flowchart.

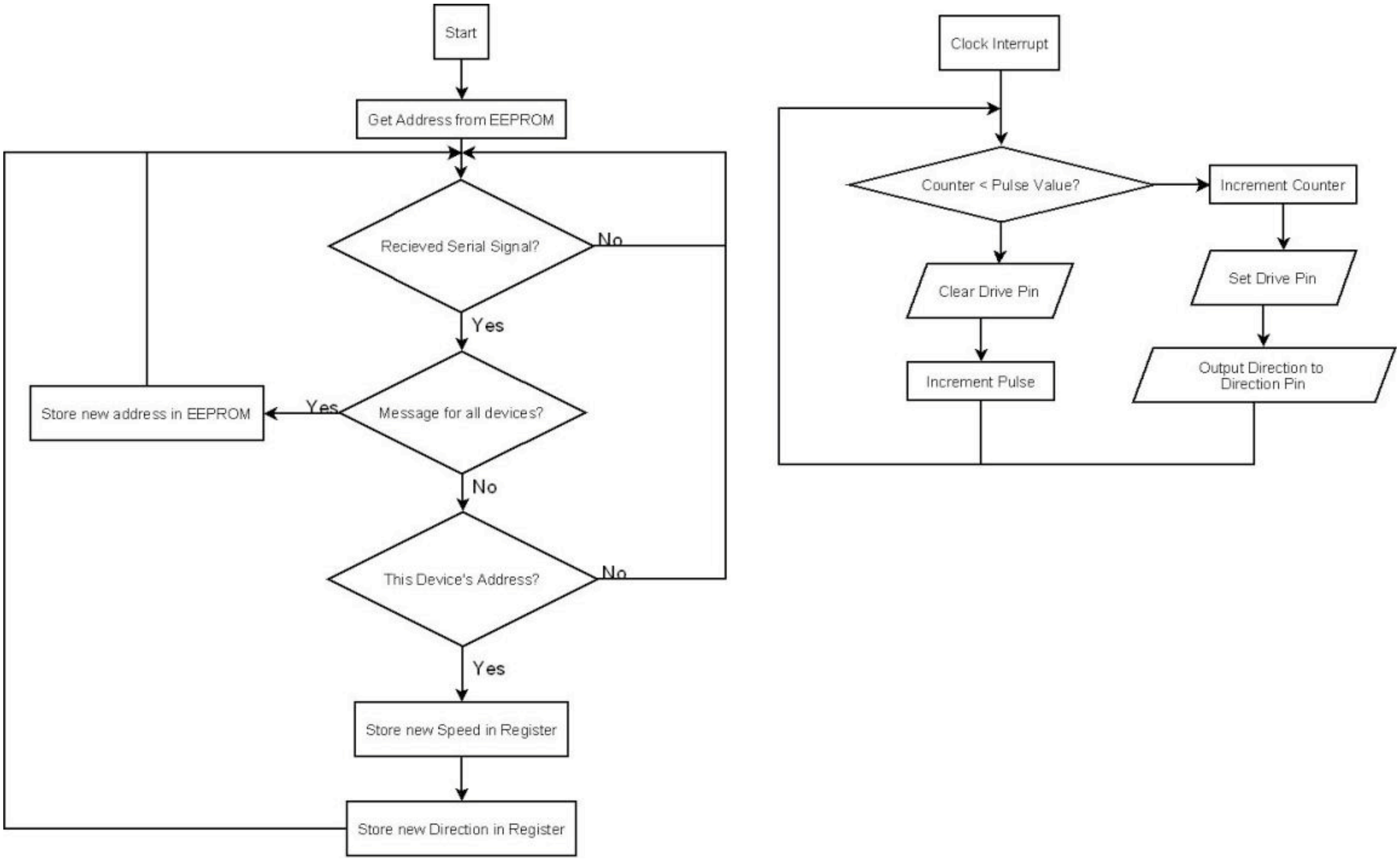

Figure C2. PIC microcontroller flowchart.