Eastern Edge Robotics

Marine Institute and Faculty of Engineering, Memorial University

Technical Report

MATE International ROV Competition 2010, Explorer Class

Team Members

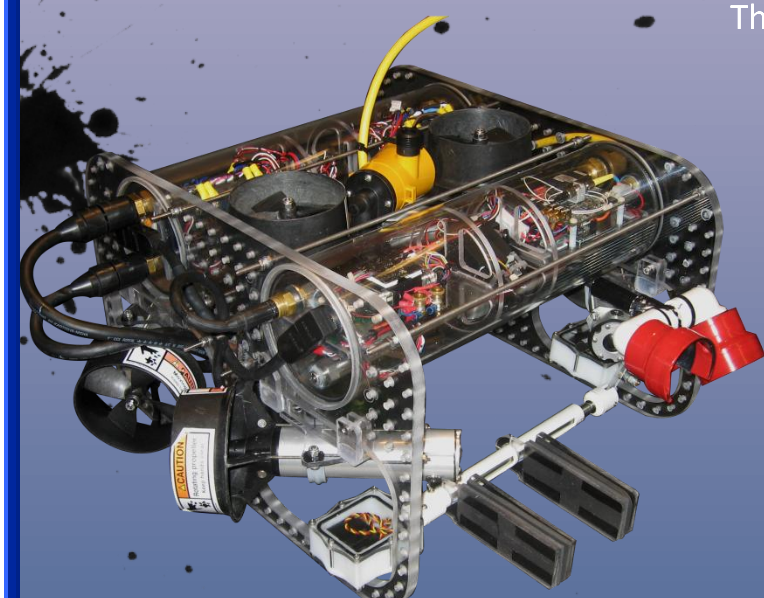
Josh Barnes, Leanne Brockerville, Cait Button, Hazel Dalton, Gavin Diamond, Mark Flynn, Scott Follett, Mikhail Freeman, Andrew Furneaux, Justin Higdon, Nancy Hillier, David Hornell, Jonathan Howse, Andrew Maillet, Petros Mathioudakis, Matthew Miné-Goldring, Reneé Quick, Bethany Randell,Daniel Ryan, Erin Waterman, Jon Watson

Mentors

Clar Button, B. Sc, B.Ed., M. Sc.

Thomas Donovan, B.A., B.Ed., Dip. Tech. Ed.

Dwight Howse, M. Eng., M.B.A.



ROV TUZO

ABSTRACT

This technical report describes the ROV *Tuzo*, built by the Eastern Edge Robotics team for the 2010 MATE International ROV Competition. *Tuzo* was designed to perform tasks relevant to the research of underwater volcanoes such as Hawaii's Loihi seamount. The process of building the ROV and traveling to the MATE Competition cost approximately $70,000, including the value of donated materials. Two waterproof clear acrylic cans containing the ROV's electronics and two Lexan™ skids form the basis of the chassis, which integrates six 48V thrusters and two high resolution, low-light cameras. Also incorporated are five main payload tools: a multi-purpose manipulator, a hydrophone and amplifier for measuring sound frequency, a rotating brush and a net for collecting crustaceans, a thermistor for measuring water temperature, and a vacuum pump for sampling a bacterial mat. The control system, programmed in C#, is based on a client server model which allows multiple and potentially remote access to the ROV system. *Tuzo* has an onboard electronics system that is contained in two team-built acrylic tubes and is connected to the surface using a custom-built tether. The topsides electronics consists of an embedded computer system controlled by a joystick. A major innovation this year was the elimination of an external notebook for ROV control, which was replaced by an embedded computer designed and built by the team. 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 2010.

***back row** (left to right): Andrew Furneaux, Dan Ryan, Jon Watson, Justin Higdon, Mark Flynn; **middle**: Cait Button, Leanne Brockerville, Andrew Maillet; **front**: Bethany Randell, Renee Quick, Petros Mathiodakis, Dave Hornell, Hazel Dalton, Mickey Freeman, Matthew Miné-Goldring.*

Table of Contents

1. BUDGET AND FINANCIAL STATEMENT

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

ITEM	DONATIONS	EXPENDITURES
Electronics cans		300.00
Topsides electronics		1900.00
Hardware (fasteners, drill bits, etc.)		300.00
Inuktun thrusters (6 x $ 2000)	12,000.00	
Fiber-optic tether - Leoni Elocab	1200.00	
Cameras (2 x $180)		360.00
Analog input board		150.00
Servo controller boards		120.00
Fiber-optic interface board – Focal Technologies - Moog	3500.00	
Lexan polycarbonate sheet		500.00
Pulse width modulators (8 x $250)	2000.00	
Misc. electronics components		500.00
Pressure Sensor – Keller America	575.00	
Digital Compass		300.00
SubConn Connectors	400.00	
Group airfare (20 people x $1125)		22,500.00
Accommodations, meals, ground transportation (20 people x $1085)		21,700.00
TOTAL	**$19,675.00**	**$48,630.00**

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
Government/Industry Contributions	10,000.00
Individual contributions (17 people @ $600.00 each)	10,200.00
Student Innovation Fund, Memorial University	2000.00
Summer Robotics Camps	8430.00
Donated materials	19,675.00
TOTAL	**$68,305.00**

2. DESIGN RATIONALE

The thrust of the design for *Tuzo* centered on the missions for this year's competition. This includes the standard requirements for speed, stability, maneuverability and vision, while maintaining a compact frame. This year's mission also entails the challenges of:

- precision movement and holding in position
- avoidance of lines and obstacles in the mission area
- performance of an assortment of different tasks

Consequently, the design rationale this year focused on:

- an ROV design which was compact and streamlined, with minimal protrusions to catch on any of the mission props
- proportional control of movement to permit precision movements in close quarters (as are required in the cave)
- complete vision in the vertical plane to permit situational awareness and effective viewing of the mission tasks during performance
- compact, effective and multi-purpose tools to fit in the limited space of the frame

2.1 Structural Frame

The chassis of *Tuzo* has been designed to support a bi-directional ROV (*Figures 2 and 3*). The major structural components of the chassis were designed using SolidWorks™ 3-D CAD and include pairs of symmetrical skids and tubes. The skids, which are constructed from 1.27cm [1/2"] Lexan™ polycarbonate, support the two lateral optically clear acrylic tubes. A 2cm grid pattern of holes has been drilled into the skids to allow for attachment and easy rearrangement of tools and thrusters. This will enable the chassis to be reused for future competitions. The two acrylic tubes have a 12.7cm [5"] outside diameter and house the ROV's electronics. Truss rods run between the two skids, parallel to the tubes, and place the tubes in compression for lateral strength. These tubes are sealed by o-rings incorporated in 1.27cm [1/2"] caps on either end of the tubes. They have been successfully pressure tested at a depth of 3.5m for two hours. The tubes, which also provide buoyancy, are at the top of the skids. This allows the thrusters, which are the heaviest components of the ROV, to be attached below for greater stability. A flow analysis of the chassis may be found in Appendix A.

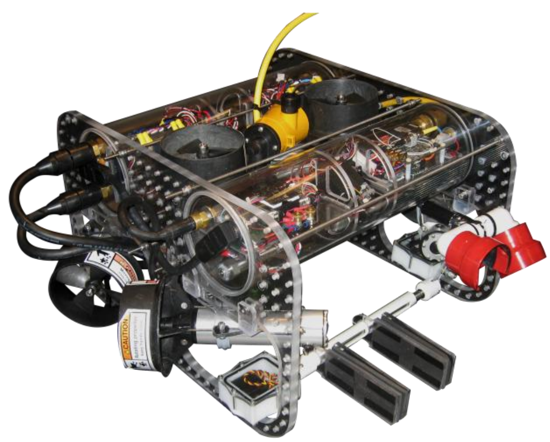


Figure 2. ROV Tuzo chassis.

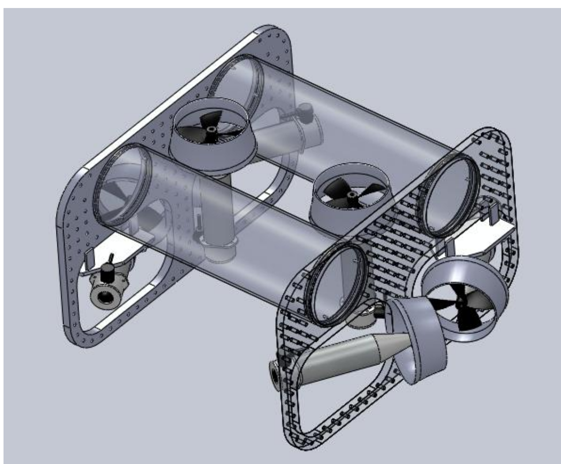


Figure 3. Solidworks diagram of Tuzo.

2.2 Propulsion

Tuzo 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, the thrusters are now outfitted with compatible Maxon™ motors that operate at 48V and 90W.

The thrusters are configured to provide five degrees of freedom. Each skid of the chassis supports one vertical thruster (centrally mounted) and two horizontal thrusters mounted at 30° from the longitudinal direction.

Figure 4. Inuktun™ thruster.

2.3 Camera

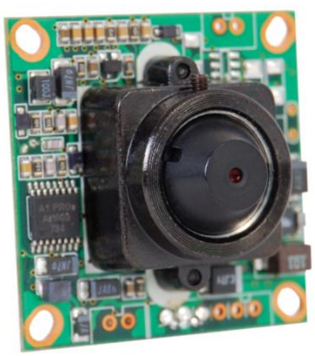


Figure 5. Super Circuits camera.

Tuzo uses two Super Circuits PC823UXP high resolution (460 TVL), low light (0.5 Lux) pinhole cameras (*Figure 5*). Each camera has a 0.85cm (1/3") color CCD and provides a 90° horizontal field of view in water. One camera is located in the centre of each of the communications and motor control cans. Cameras are tilted using servo motors to give 360° of viewing in the vertical plane.

2.4 Safety Features and Precautions

Safety was a major concern of the Eastern Edge Robotics Team throughout the whole process of design, building, development and testing of the ROV *Tuzo.* Team members received training from mentors in workshop safety for shop operations and procedures and power tool use.

ROV *Tuzo* has a number of safety features, including:

- circuit protection and kill switch for emergency stoppage
- completely shrouded thrusters to prevent accidental injury
- rounding and removal of all sharp edges
- temperature and humidity sensors inside the onboard containments to forewarn of overheating or leakages
- electrical isolation of the high power motor components and the low voltage electronic components in separate waterproof cans
- double O-ring protection in sensitive electronics and motor containments
- secure tether attachment and strain relief to avoid breakage or damage
- warning signs located near moving components and electrical hazards

Operational precautions included:

- careful stowage, deployment and management of the tether during mission operations to avoid tripping
- a protocol in the pre-dive check operations which requires power off, except when "All-clear" is designated by the deck manager
- life jackets required for all deck crew during testing
- training and practice in safety protocols

3. CONTROL SYSTEM

The control system for *Tuzo* is an upgrade of the system originally designed in 2007 for the ROV Bartlett, and runs as a Windows Communication Framework service hosted as a windows service. It improves on the original by enforcing a strict three-tier object oriented architecture design (device libraries, application logic, and user interface) written in C#. A programming flowchart can be found in Appendix B.

3.1 Libraries

The design of the control system facilitated the development of libraries of objects that can be used with any ROV that uses the same design pattern. The end result is an easily modifiable and customizable system, where library objects are considered atomic. Currently the software has a device library (pressure sensor, accelerometer, etc.) and libraries for logics (UI level, Application level). Any device can be interchanged to give the ROV different functionality based on available hardware.

Atomic device objects allow the developer to use the pre-made building blocks (objects), instead of writing and modifying code for each new ROV. Coupling the new architecture with rigorous unit testing ensures that the atomic objects are bug-free and stable. This reduces debug time by limiting possible problems to a particular new code section.

The devices for the ROV are not the only atomic pieces. Logical units, such as motor control and auto-navigation (auto-depth, auto-pitch, auto-roll, auto-heading), also minimize the chance of errors for new or returning developers since they do not need to be modified.

An important feature of the architecture is that all device objects are designed to operate with inputs and outputs of the range ±1000. This means that any device will always produce maximum output with a +1000 signal, and minimum output (sometimes reversed output) with -1000. The devices will also output in that range, such that its maximum input value is +1000, and its lowest output value is -1000. This common value set not only makes it easier to pass information around, but it also makes device conversions easier. The output of one device can be tied directed to the input of another. This could create interesting combinations, such as a motor controller linked to the depth sensor's output. A ±1000 resolution significantly exceeds human precision while providing sufficient range to prevent rounding errors.

The abstraction of objects (making them universal for any implementation of the ROV) allows us to easily modify the software to operate a different ROV.

3.2 Application Layer

An implementation of an ROV is accomplished by writing new logical connections between building blocks. The logical connections operate with a given minimum set of functions, which can be used by any other component (UI, Logic Connection, Device collection). This allows for greater flexibility; for example, the UI from a previous ROV can be used on the current ROV. An obvious advantage to this design is that an older UI can be used to debug a new ROV system, before its UI is written, saving on design time. Mixing and matching components in our system allows us to develop a large testing UI, and even ROV simulation, which can be used for various tasks during the development.

Windows Communication Foundation (WCF) provides a framework for remote communication between programs, which allows us to run our control software on a computer connected to the ROV, while having the UI operate on a remote machine. This physical division between the UI and Application levels further ensures that the architecture constraints are not violated and opens the door to the possibility of an on-board computer in the future. With a wireless connection to the ROV, during testing, multiple developers can test and debug the ROV, using multiple client machines. This style of testing means that, in the case of an anomaly, a debugger can connect to the ROV to get vital information that the actual UI may not be displaying.

A side effect of this convenience is that multiple users could connect to the system. To fix this problem the system was designed to allow a "Power User" to connect. The Power User function was designed such that once it attempts a connection, all other clients are blocked from accessing the system - this is vital if some client is malfunctioning.

Running our software as a windows service means that it is always resident. This also means that our previous paradigm of "set and forget" for thruster control was not appropriate. It was a safety issue since if the thrusters were turned on and the client loses connection to the ROV, then the ROV would continue to operate the thruster. This would mean that the ROV could not be stopped. To fix this, we designed our control system to use heartbeat signals with outputs. If a heartbeat has not been seen in a given timeframe, then the control would run a default signal, which in the case of thrusters would stop the ROV.

3.3 Graphical User Interface

The graphical user interface (GUI) (*Figure 6*) is based on a windowed concept developed during the 2009 competition year. It allows the pilot to section off the GUI into manageable windows that can be opened or closed when needed. The GUI is split into six windows: the main operations window, ROV navigation, thruster power control, environmental data, electrical information, and external temperature data. The GUI communicates with the ROV system through the topsides computer service. This allows the control system and interface to remain separate from each other, meaning multiple interfaces can exist for a single ROV control system based on operation specification. Advancing on last year's video interfacing, the video feeds of the ROV have been separated from the control interface in favor of a third party software, AMCAP. This software runs multiple instances of itself for interfacing the video capture card's multiple inputs in the topsides computer. The ROV's hydrophone is linked through the topsides computer via the built-in audio card which is interfaced through a separate third party software, Audacity. Audacity allows the operator to hear and see the output of the hydrophone in real time in order to analyze potential rumbling sites.

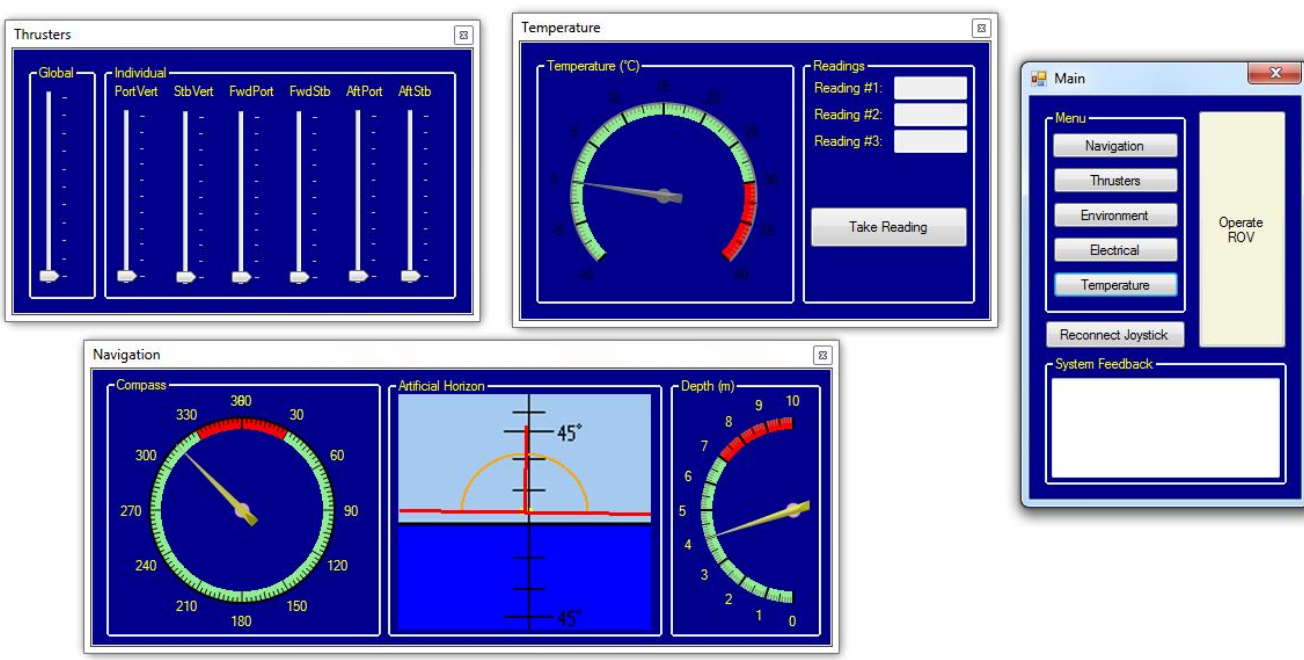


Figure 6. Graphical user interface.

3.4 Code Management

To reduce the number of conflicting changes in our code, each developer worked with only one of the three tiers, which meant that they could progress simultaneously. The downside of working simultaneously was that the design phase of the software needed to be completed before any development began. This can be particularly difficult for team members who are not familiar with software development processes. Our robust design of the software allowed us to have all necessary documentation completed long before any work began.

In previous years the team faced problems when managing digital files, especially source code. Frequently files were e-mailed and deposited in online repositories to distribute the files to those who needed them, and delays occurred while attempting to track them down. This year subversion (SVN) allowed us to establish a source control for any digital documents, including source code. SVN is designed to allow multiple users to modify the same files at the same time. It also supports creating snapshots of a file at a particular time (Tagging), which we used to indicate stable versions of the code.

We were fortunate enough to gain access to the SVN server at Memorial University's Computer Science department, which was an optimal choice because it's a dedicated server that we can count on being available at all times. Since our team is associated with the University, this also allows us to pass the repository on to new members when our old members retire from the team.

4. ELECTRONICS

The electronics system has four key components: the topside control unit, the tether, the submarine communications can and the submarine motor control can. See *Figures 8* and *9* for Electrical Schematics of these components.

4.1 Topside Control Unit

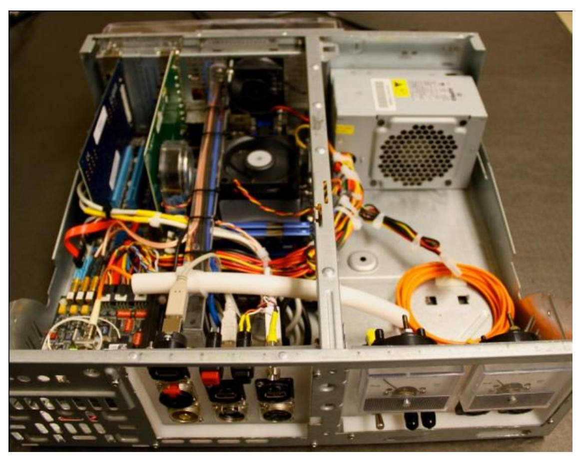


Figure 7. Topside control unit.

The topside control unit provides electrical protection as well as communication to the ROV (*Figure 7*). From the main 48V DC power input, power is routed through a 20A circuit breaker, voltage and current meters and then to the ROV. The topsides controller contains a purpose-built computer based on a μATX form factor motherboard. This computer has 4GB of RAM, a quad-core CPU, and a 100Gb solid-state hard drive. This provides plenty of capability for control, video and audio processing for the ROV system. In addition, the computer's HDMI output allows for connection to a high definition monitor (1920x1080P), which displays the ROV's GUI and camera feeds. These feeds are captured using an Adlink 4-port video input card. In addition, a B&B Electronics 8-port RS232/422/485 serial interface card is used for data communications to the ROV. Both of these cards are connected to the topsides unit of a Model 907 video/data multiplexer from Focal Technologies™. This unit allows for communication to the ROV over a single fiber strand. All of the six serial data channels (2x RS485, 4xRS232) on the multiplexer are connected to the serial interface card but only two of the three available video channels are connected to the video capture card. The third video channel, which has been converted to carry an audio signal for use with the hydrophone, is connected to the line level audio input on the motherboard's integrated sound card. In addition, the topside computer is powered from a standard 120V ATX power supply and all communications to the ROV are though fiber optics. This results in the topsides control unit being electrically isolated from the ROV unit, providing an added degree of safety for both the operators and the sensitive electronics in the topsides computer.

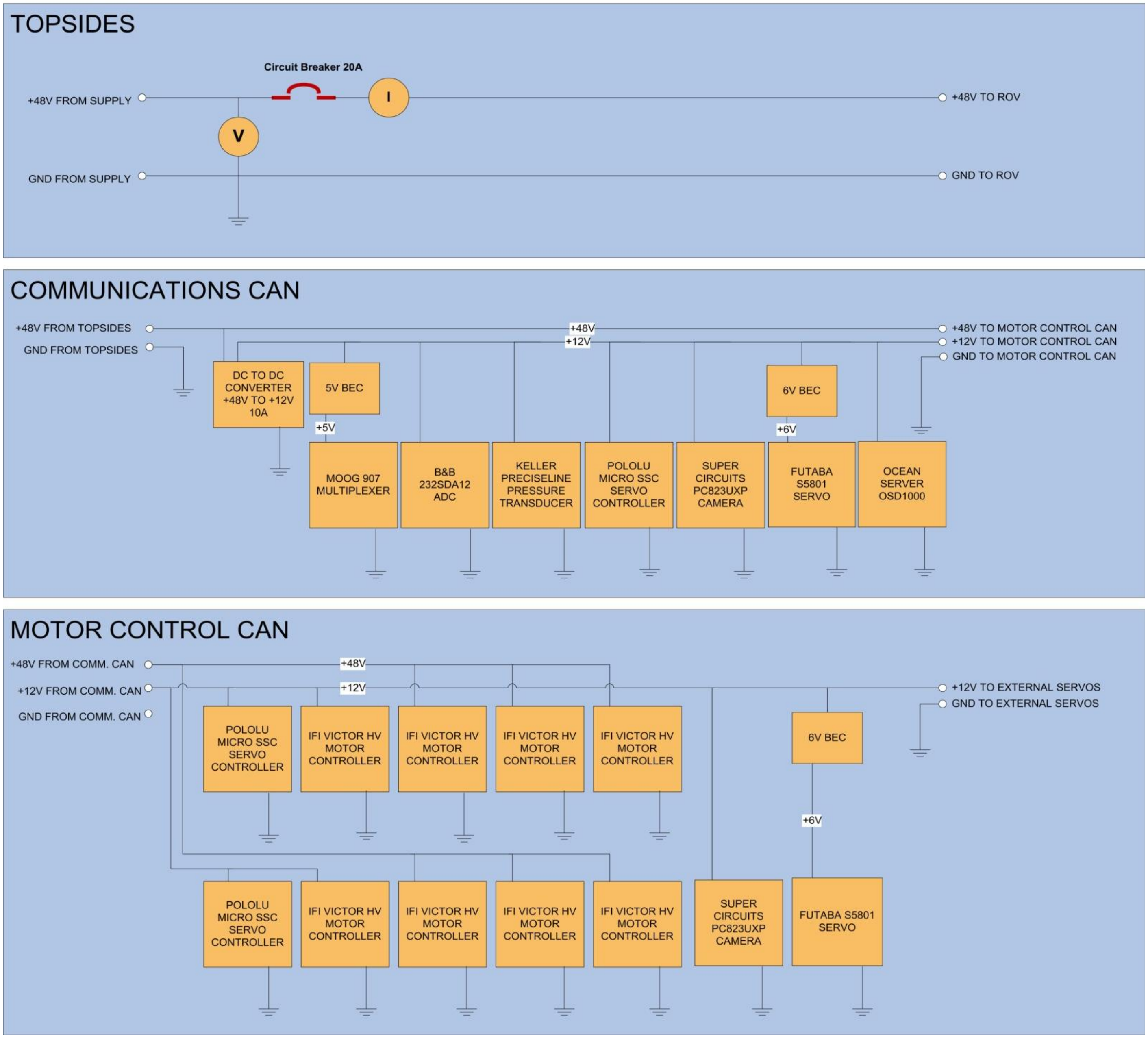


Figure 8. Electrical schematic of power distribution.

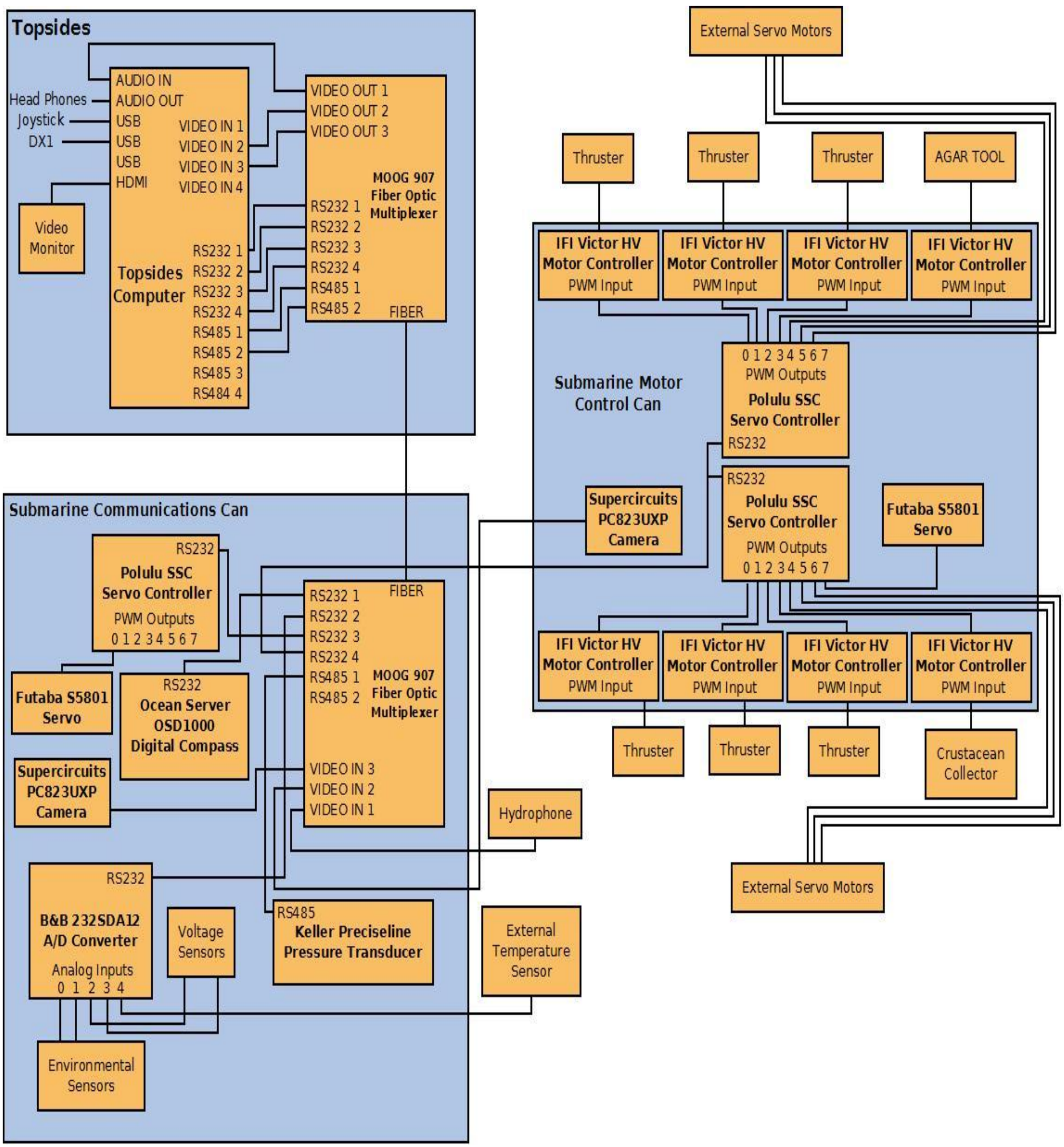


Figure 9. Signal flow diagram.

4.2 Tether

Figure 10. Custom-designed tether.

Leoni Elocab Inc. of Kitchener, Ontario, Canada, donated a custom tether designed by the team (*Figure 10*). The outer portion of the tether has a low drag polyurethane coating and was designed to make the entire tether neutrally buoyant in fresh water. The tether has two 16-gauge copper wires to carry DC power, and two multi-mode fiber optic strands for control and video signal transmission. One of the fiber optic strands is redundant and will only be used if the other is damaged. The tether is terminated on the topsides end with a quick disconnect Speakon™ type electrical connector and two ST type optical connectors. On the submarine end, a brass penetrator that was custom-machined by the team is used to carry the tether into the submarine communications can. It is terminated electrically with ring terminals to the ROV's power distribution lugs and optically with two more ST connectors.

4.3 Submarine Communications Can

The main onboard electronics, which provide communications to the surface, are located a waterproof clear acrylic tube (*Figure 11*). The tube measures 12.70cm (5") O.D. x 40.64cm (16") long and has a custom-machined polycarbonate end cap at each end. Multi-pin bulkhead connectors made by Subconn provide an electrical connection to the outside. Inside the can, multiple devices provide data and signal acquisition, as well as communications to the surface. Also, a DC-DC converter in the can drops the 48 volt input down to 12 volts and supplies it to the 12V rail. The converter is rated for up to 60 volt input voltage and 10 amps current.

The remote unit of the Model 907 multiplexer conveys the serial data as well as the analog video and hydrophone signals to and from the surface. An A/D converter from B&B Electronics monitors power and environmental conditions on the ROV. It connects to the multiplexer via RS-232 and has 12-bit resolution over a 0-5V range for each of its 11 inputs. To ensure proper voltages in the electronics can, power supply voltages are sampled though voltage divider circuits. Internal temperature of the can is monitored to ensure that components inside the can are not overheating 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 that will record humidity from 10-95% rH. A connection from A/D converter to outside the can is also provided for the 0-5V output from the external temperature sensor.

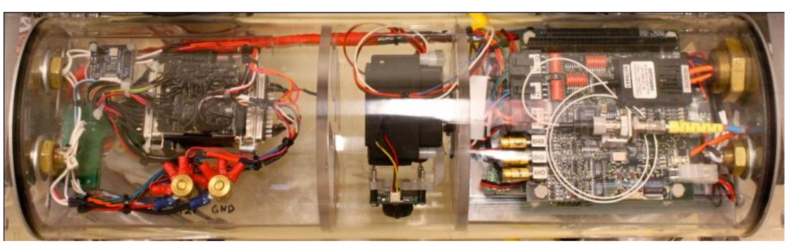


Figure 11. Submarine communications can.

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.

A Preciseline™ pressure transducer from Keller America is used to measure water depth. Its measurement opening is threaded into a hole in one of the end caps and the device communicates 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.

A Pololu™ 8-channel servo controller is used to control a servo motor that tilts the onboard camera encased in the submarine communications can.

4.4 Submarine Motor Control Can

The submarine motor control electronics are housed in a can similar to the communications electronics (*Figure 12*). Two Pololu™ 8-channel servo controllers share a RS232 connection from the communications can. They output 16 pulse width modulated signals. Six of these signals are fed to six IFI Robotics Victor™ HV pulse width modulators (PWMs) supplied with 48 volts, which are in turn connected to the six thrusters providing individual proportional control. Two more signals from the servo controller are fed to two Victor HV PWMs supplied with 12 volts for control of tooling. The remaining signals are fed to external servo motors (for tooling) and to the servo motor that tilts the second onboard camera.

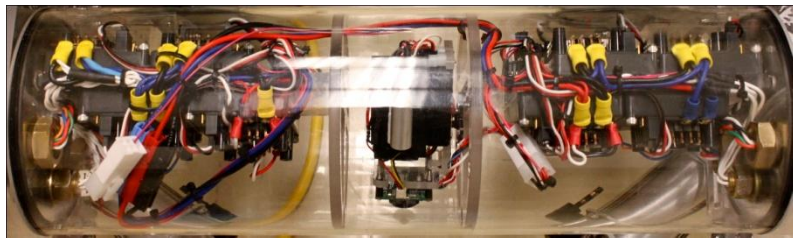


Figure 12. Submarine motor control can.

5. PAYLOAD TOOLS

5.1 Task 1: Resurrect HUGO

This task requires *Tuzo* to remove two steel pins from the Elevator frame, releasing the High Rate Hydrophone (HRH), and in turn maneuver the HRH to the determined earthquake site. Once this is complete, the connector needs to be retrieved and plugged into HUGO. To accomplish this task, the team designed a multi-handed gripper that is articulated by two waterproof servo motors (*Figure 13*). The assembly itself is made up of four hands, two of which are fixed to the gripper frame which is constructed of 1.3cm (½”) PVC. The other two hands are connected to a 0.95cm ($^3/_8$”) length of unthreaded stainless steel rod, coupled to the actuation crank, and perform the ‘open/close’ motion using one of the waterproof servos. Each hand is fabricated from 0.64cm (¼”)-thick Lexan™ sheet and covered with a foam layer to provide flexibility and additional gripping force. The two pairs of hands are evenly spaced across the front of the ROV to provide multiple locations to perform the various tasks. The second servo allows the entire unit to rotate to a 45° orientation to properly install the

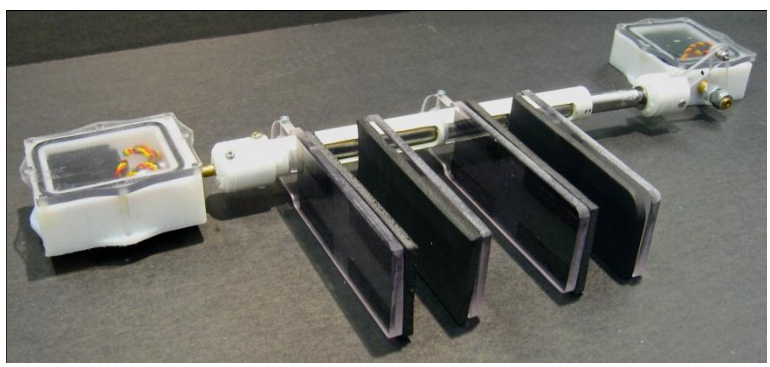


Figure 13. Manipulator.

connector, and can also rotate all the way back to reach the storage area within the chassis. Each of the fixed hands is equipped with a magnet to assist in removing the two pins.

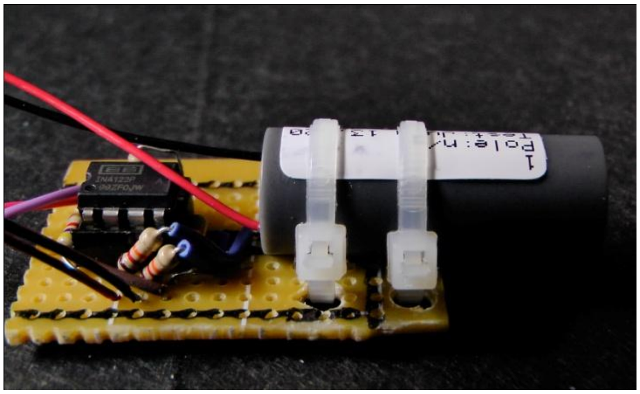


Figure 14. Hydrophone and amplifier before potting.

For the task of measuring the sound frequency, we used a small-diameter hydrophone from Sensor Tech (*Figure 14)*. It has a voltage sensitivity of -202 dB and a maximum operating depth of 3500m. An amplifier for the hydrophone was custom designed and built by the team using an INA 122 instrumentation amplifier set with a gain of 100. The amplifier was built on a prototyping board and sealed inside a PVC tube with epoxy. An audio transformer and clamping circuit are located inside the ROV's onboard electronics can. This produces a signal with -0.7 to 0.7 volt range. The signal uses a video port on the fibre-optic multiplexer and is read by the topsides computer. A circuit diagram is provided (*Figure 15*).

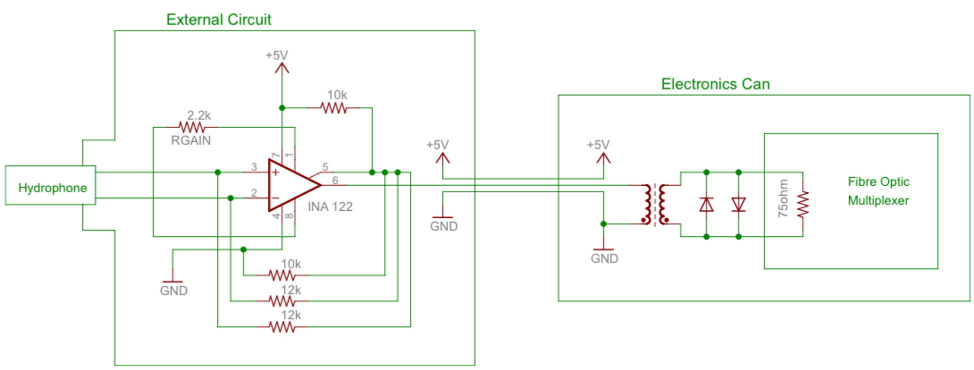


Figure 15. Amplifier circuit diagram.

5.2 Task 2: Collect samples of a new species of crustacean

The tool designed for this task utilizes two rotating brushes and a collection net mounted on the ROV (*Figure 16*). A 750 GPH bilge-pump motor spins the brushes via a gear train through a 9:1 gear ratio. The gears and brushes are from a Bissell Powered TurboBrush Hand Tool. Three of the Bissell brushes are connected together, resulting in a total length of 35cm. All the components are mounted in a Lexan© frame measuring 30.5cm x 10.2cm x 7.6cm. The Lexan was bent to form a bracket-like shape and then cut at approximately 16 degrees; this cut eliminates excess surface area. Once the pilot has navigated the ROV through the cave, the motion of the brushes lifts the crustaceans off the back wall

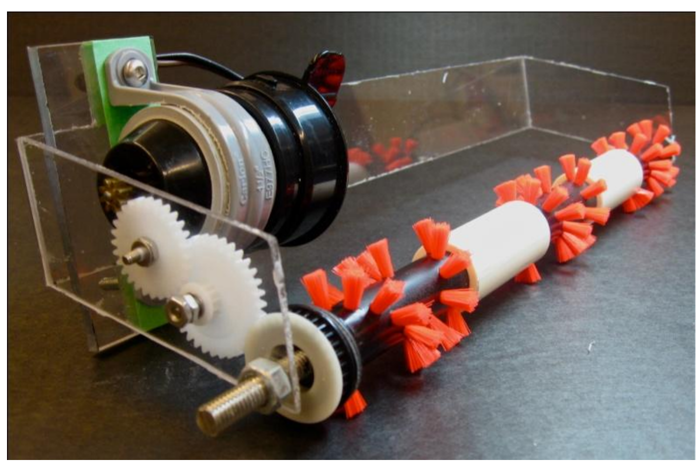


Figure 16. Crustacean collection tool.

of the cave and into the collection net. Another piece of Lexan, mounted at the front of the bracket and under the brush, prevents the samples from exiting the net while still in contact with the brush. *Tuzo* carries two copies of this tool, one of which is mounted at the top and the other at the bottom edge of the ROV. This allows for collection of both the highest and lowest crustacean samples.

In case of any difficulty with this tool, the manipulator described in Task 1 can be successfully used to retrieve the crustacean samples, albeit less efficiently.

5.3 Task 3: Sample a new vent site

For the task of measuring the water temperature at a newly discovered underwater vent, we used a small thermistor inside a PVC tee that seals on the venting object and allows the venting fluid to flow through (*Figure 17*). We chose a thermistor for this task because of its small size and subsequent fast and accurate temperature reading.

Tuzo has a Negative Temperature Coefficient (NTC) thermistor purchased from General Electric, and an amplifier that was custom-designed and built by the team. Thermistor part #MC65F103A measures temperature using a voltage divider as input to an INA122 instrumentation amplifier, set with a gain of five. This produces a voltage between 0-5 V for a temperature range of 0-58ºC that the A/D converter can read.

Figure 17. PVC tee with encased thermistor.

On each end of the PVC tee, a plastic fitting was made to fit over the vent. The left fitting is angled down at 45° to fit over the bottom and middle vents. The right fitting is horizontal to fit over the top vent. Each fitting has a foam ring on the inside that provides a tight seal on the vent opening. When the ROV places one of the fittings on a vent, the fluid flows into the fitting, through the PVC tee, past the thermistor, and out through the other fitting. In this way, the tool can be used measure the temperature at all three heights on the vent.

This task also requires that the ROV retrieve a spire from the vent site. *Tuzo* accomplishes this goal by use of the manipulator described in Task 1.

5.4 Task 4: Sample a bacterial mat

This task requires that the ROV collect a sample of a bacterial mat, which is simulated by a 7.5 cm deep bowl of agar gel. The method used by *Tuzo* to sample this agar is a vacuum pump (*Figure 18*). The pump is a Mayfair™ 12V submersible live well pump attached to the end of a 6.25 cm diameter coring cylinder, which consists of a 12 cm length cut from a clear Lexan™ water bottle. The dimensions of the coring cylinder accommodate approximately 160ml of agar in one sampling. The sampling action is simply to maneuver the open end of the coring cylinder to the top of the agar and turn on the pump, creating a vacuum inside the cylinder. The vacuum pulls and downward thrust pushes the coring cylinder into the agar to the bottom of its containment, separating it from the remainder of the

Figure 18. Vacuum pump tool.

agar material. The vacuum in the cylinder is then maintained at a reduced level to keep the bacteria (agar) sample inside the cylinder, until it is removed at poolside.

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, last year we started using an open-source application called Dropbox™ (http://www.getdropbox.com) which allows synchronization and version control of important electronic files. This year, we have expanded our use of Dropbox™ to include SolidWorks™ drawings, software source code, schematics, and communications components 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.

In addition, this year presented a special challenge for Eastern Edge Robotics in that many of our most experienced members graduate this year and thus will not be returning to the team. This meant that we had to ensure that the knowledge and expertise gained by these members during their involvement with the MATE Competition was passed on to newer members. To aid in this process, we specifically allocated a small group of the newer team members to work under each of our graduating members for the year. In this way we were able to guarantee that their skills would be passed on to multiple team members - in case some of these newer members do not return next year - and continue to benefit the Eastern Edge Robotics team.

7. TROUBLESHOOTING TECHNIQUES

A major challenge that required troubleshooting this year involved the waterproofing of servo motors by designing and manufacturing a waterproof servo box. These waterproofed servos are crucial in the operation of our two-axis manipulator tool (see Section 5.1). Each waterproof servo box encases one HiTech™ servo motor, a 5 volt regulator, aluminum torque coupler, and a brass torque shaft, which protrudes out of the box.

In previous years, there were many attempts at waterproofing servos by pressure compensating them with oil, installing o-rings, and encasing them in rubber, which resulted in little success. This year, we wanted to take up the challenge of waterproofing the servos by placing them in a box. The first design we came up with was simple, with a flat face on the opening of the box and using a gasket to seal it. Also, a shaft from the servo penetrated through the box using a bulkhead connector, originally for electrical conduits. Unfortunately, when we pressure tested these prototypes with three different gaskets and configurations, they leaked. As these waterproof servos were a determining factor for how our manipulator was to be operated, development of a new, more effective design was critical. Numerous possibilities to the source of the leak were listed, including: mounting holes through the gasket, the gasket in general, and the electrical conduit bulkhead connector.

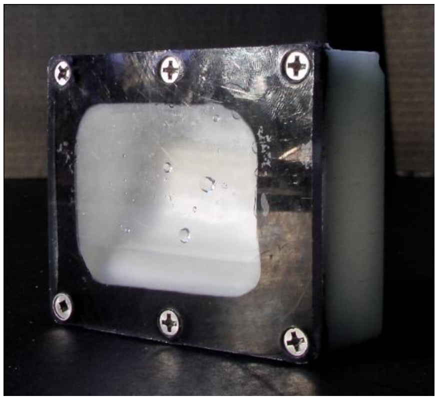


Figure 19. Leaky (top) and successfully waterproofed (bottom) servo boxes.

To improve upon our previous design and address possible sources of leaking, the design of the servo box was modified in a couple of ways. First, instead of a gasket, an o-ring placed in a groove on the face of the opening was used to improve the sealing. Second, instead of using the electrical conduit bulkhead connector to penetrate the shaft, we replaced this with two o-rings within the wall of the waterproof servo box. By implementing both of these improvements, we were able to reduce the overall size of the servo box as well.

These new waterproof servo boxes were pressure tested, along with our electronics cans, in four meters of water (*Figure 19*). They successfully remained watertight over two hours later.

8. FUTURE IMPROVEMENTS

One improvement that our team has been hoping to implement for some time is design and build our own brushless thrusters with embedded PIC controllers. These would be more reliable, efficient and durable than our current commercial thrusters.

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) 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 slip rings 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.

iii) Simulation software for robotic arm training and autonomous programming.

Figure 20. Jon and Hazel building the topsides computer.

9. LESSONS LEARNED

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. Starting last year, the team utilized an array of USB video input devices in order to begin bringing video feeds directly from the ROV into the laptop computer on the surface. Although successful, the lack of reliability in USB sent the team looking for an alternative solution for this year. Our solution was the construction of a topsides controller box that included a topsides computer built into it, eliminating the need for USB video inputs and making for a more stable operating platform.

The topsides computer includes two PCI controller cards, an eight-port serial interface card and a four channel video capture card. The number of video feeds last year was limited to two due to limitations in USB communication. Although this was not an issue at the time, for future improvement, the addition of the four channel video capture card allowed for the simultaneous viewing of multiple video feeds, thus removing the limitation USB places on our feeds. The serial communication card eliminated the need for a USB hub in the controller box handling all the communication devices in the topsides controller, increasing the reliability and standardizing all communication ports within the control software. Learning from last year's issues with USB communication, this new system has saved the team a lot of time in the areas of programming and creating solutions to compatibility issues between the laptop controller and the ROV's control hardware.

Interpersonal relationships are always an important aspect in the success of Eastern Edge Robotics as we have quite a large team. This year, we have 21 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. JOHN TUZO WILSON AND THE ORIGIN OF THE HAWAIIAN ISLANDS

John Tuzo Wilson was one of the most imaginative earth scientists of his time, and widely regarded as the father of academic geophysics in Canada (*Figure 21*). One of his most significant contributions to the field was his proposed explanation of the origin of the Hawaiian islands during his research on plate tectonics.

Figure 21. John Tuzo Wilson.

Wilson was born in Ottawa, Ontario, on the 24th of October, 1908. He became the first student to study geophysics in Canada during the completion of a Bachelor of Science degree from the University of Toronto, and subsequently earned a second Bachelor's degree from Cambridge and a PHD from Princeton[1]. Wilson joined the Geological Survey of Canada as an Assistant Geologist in 1936, where he was involved in the conventional mapping of the country. During this time he pioneered the use of air photos in geological mapping and was also responsible for the first glacial map of Canada. In 1939, at the outbreak of the Second World War, he joined the Royal Canadian Engineers as a Lieutenant. He was sent overseas with a tunneling company and returned to Canada at the end of the war as Colonel, Director of Army Operational Research. He spent the time directly after the war testing army vehicles under severe Arctic and sub-Arctic conditions.

In 1946 Wilson joined the Department of Physics at the University of Toronto, accepting a highly unusual offer to start as Full Professor of Geophysics. His early research involved aging different parts of the Canadian shield. During this time he was appointed as chair of the National Committee for the International Union of Geodesy and Geophysics (IUGG) and in 1954 he became the organization's Vice President.[2]

During the 1960's, Wilson performed perhaps his most important work - refining and championing the theory of plate tectonics. Plate tectonics is the theory that the rigid outer layers of the

Earth are broken up into numerous "plates" that move relative to each other. Although this theory was long held in disrepute, it is now widely accepted. Wilson first described the Transform Fault, a common plate boundary where two plates move past each other horizontally[3]. However, his most influential publication on the subject explored the origin of the Hawaiian-Emperor seamount chain, which lies far from any mid-ocean ridge, where volcanoes would be expected to form. Wilson proposed that the chain was created by a "hot spot" of volcanic activity that is essentially stationary as the Pacific tectonic plate drifts in a northwesterly direction, leaving a trail of volcanic islands and seamounts in its wake. Wilson later attributed his interest in Hawaii to an ascent of Mauna Loa he had undertaken with his wife years earlier.[4]

In the same decade, Wilson also studied the life history of oceans and described the Wilson cycle of oceans - the opening and closing of oceans over time due to continental drift. In 1967 he became Principal of the newly established Erindale College at the University of Toronto, where he remained for 7 years before retiring as Professor Emeritus in 1974. Wilson also served as the President of the Royal Society of Canada from 1972-73, Director General of the Ontario Sciences Centre from 1974-85, and Chancellor of York University from 1983-86.[5]

During his lifetime, Wilson received over 20 different honours, awards and medals, including Officer, Order of the British Empire (1946); Order of Canada, Companion (1974); Civic Award of Merit and Gold Medal, City of Toronto (1960); Gold Medal, Royal Canadian Geophysical Society (1978); and the Encyclopedia Brittanica Medal and Award (1986). In addition, he held 15 honorary degrees, and two seamounts in the Pacific Ocean about 200 km west of Vancouver Island are named the Tuzo Wilson Seamounts in his honour.[2]

John Tuzo Wilson's accomplishments and contributions to science remain extraordinary in both scope and significance, and inspired us to name our ROV *Tuzo*. He died in Toronto on April 15, 1993.

References

[1]http://particle.physics.ucdavis.edu/bios/Wilson.html
[2]http://www.physics.utoronto.ca/overview/history/john-tuzo-wilson
[3]http://www.absoluteastronomy.com/topics/John_Tuzo_Wilson
[4]http://www.absoluteastronomy.com/topics/Hawaiian-Emperor_seamount_chain
[5]http://www.science.ca/scientists/scientistprofile.php?pID=232

Photo Credit: http://asc1996.com/history1.htm

11. REFLECTIONS ON THE EXPERIENCE

Figure 22. Andrew working on the manipulator.

"This was my fifth year on the Eastern Edge Robotics team, and my interest in underwater robotics has only continued to grow year after year. Being a part of this team has made me realize that this is the field that I wish to pursue as a full time job. I am an electrical engineering student going into my fifth year of a six year program. Within my program we have the opportunity to complete up to six work term placements with a wide variety of companies across the world. I have had been fortunate enough to work with a number of sub-sea companies, and these work terms have greatly increased my knowledge and understanding of the ROV industry. The companies that I have worked for have uniformly been very interested in my involvement with Eastern Edge Robotics, as I am able to bring the experience that I've gained through participation in the MATE competition into the business setting and thus be a valuable member of a production or design group. Participation in the MATE competition has also continually challenged me to come up with new concepts, confer with other members of the team, and turn these ideas into working models. The competition not only develops these important design skills, but it also helps to encourage group interaction, production development, organization, and other skills that I have found to be invaluable in the workplace."

- Erin Waterman, 5th year student, Electrical Engineering, Memorial University

"This was my first year on the Eastern Edge Robotics team, and it has been both an enjoyable and memorable experience. Being on the team has given me a sense of responsibility, teamwork, and confidence, skills which often are not learned through regular post-secondary education. I have gained a vast knowledge of the ROV industry that I would not have gotten from a textbook or university teacher, and I think that this learning has been especially valuable due to it's hands-on nature. The skills that you gain participating in the MATE competition are truly unique, and I believe that they will be extremely valuable in a work setting. Working with students that are the same age as me, who are all in a wide variety of fields, including Biochemistry, Engineering, Computer Science, Mechanical, Electrical, and Navel Architecture has given me real-world experience that is very hard to come by. Joining the team and participating in the MATE competition has been without a doubt the highlight of my post-secondary experience to date."

- Petros Mathioudakis, 1st year student, ROV Technician Program, Marine Institute

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 23*).

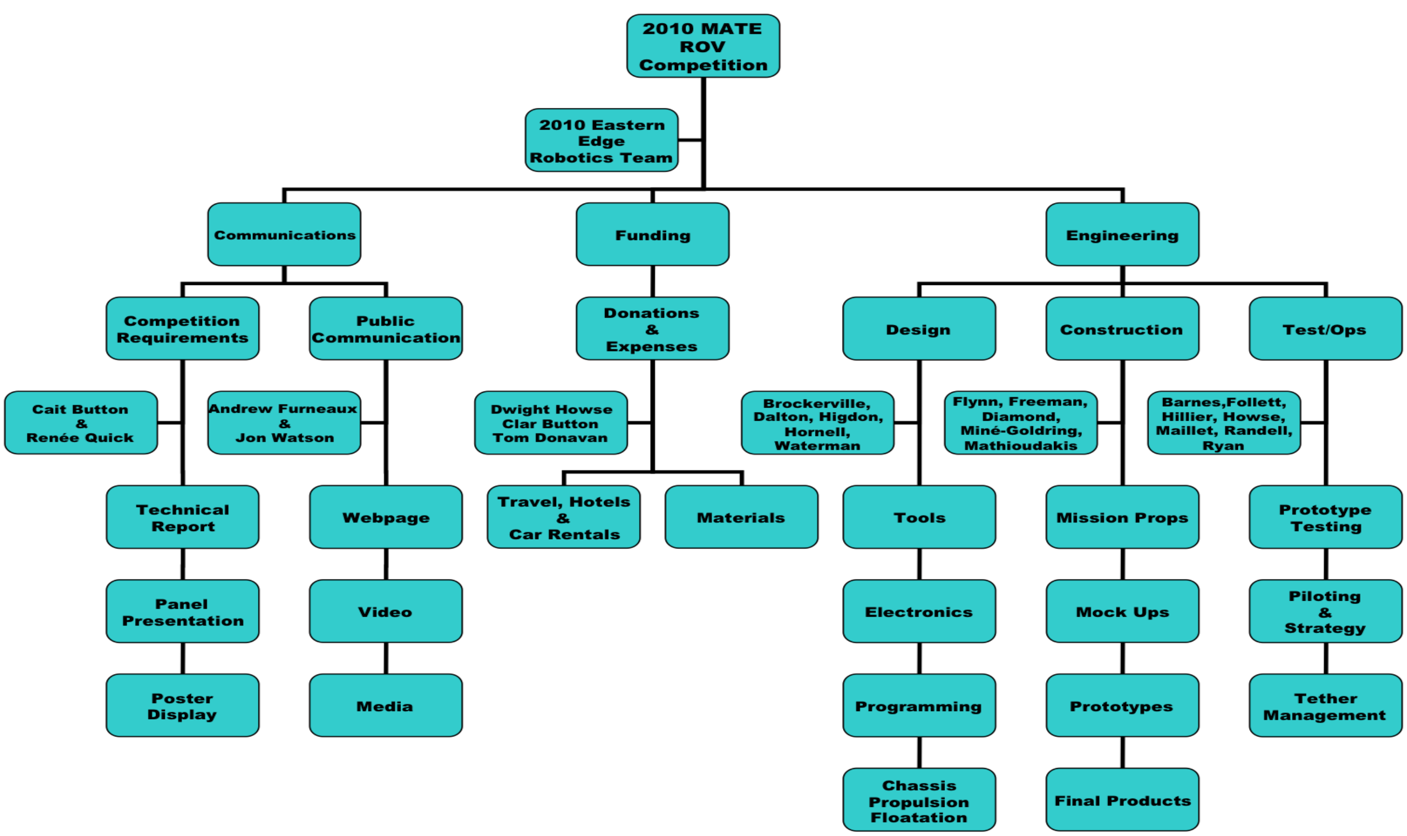
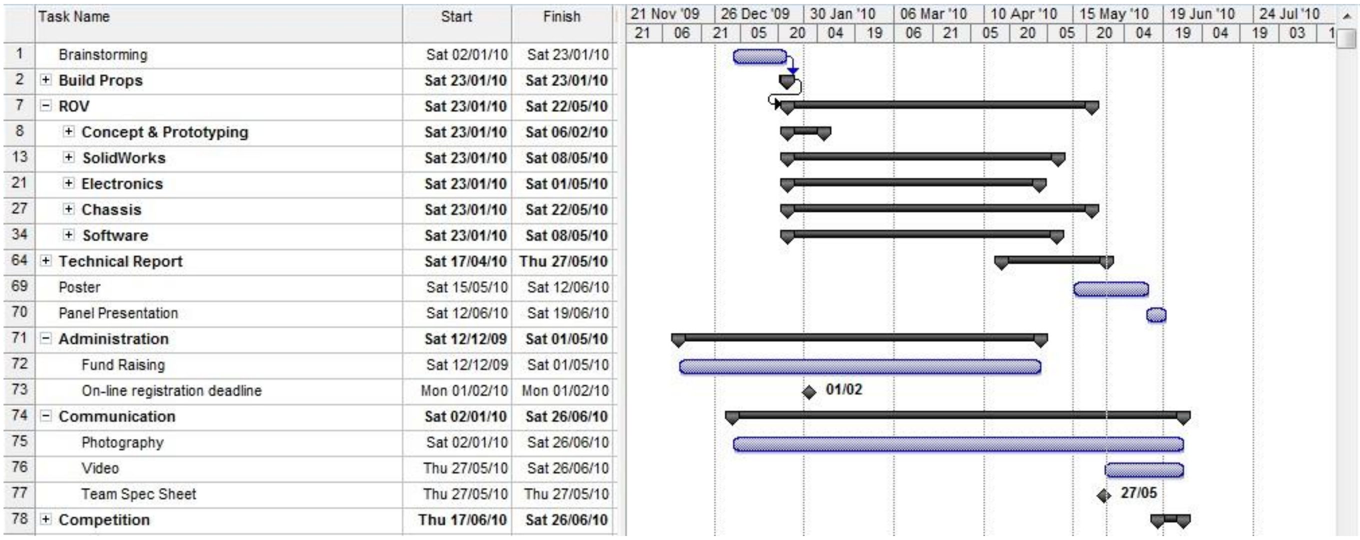


Figure 23. Team organizational chart.

To ensure that we stayed on schedule, we also completed a Gantt chart at the beginning of the year (*Figure 24*). This helped to ensure that we would have the ROV completed and as much time to practice before the competition as possible.



	Task Name	Start	Finish
1	Brainstorming	Sat 02/01/10	Sat 23/01/10
2	Build Props	Sat 23/01/10	Sat 23/01/10
7	ROV	Sat 23/01/10	Sat 22/05/10
8	Concept & Prototyping	Sat 23/01/10	Sat 06/02/10
13	SolidWorks	Sat 23/01/10	Sat 08/05/10
21	Electronics	Sat 23/01/10	Sat 01/05/10
27	Chassis	Sat 23/01/10	Sat 22/05/10
34	Software	Sat 23/01/10	Sat 08/05/10
64	Technical Report	Sat 17/04/10	Thu 27/05/10
69	Poster	Sat 15/05/10	Sat 12/06/10
70	Panel Presentation	Sat 12/06/10	Sat 19/06/10
71	Administration	Sat 12/12/09	Sat 01/05/10
72	Fund Raising	Sat 12/12/09	Sat 01/05/10
73	On-line registration deadline	Mon 01/02/10	Mon 01/02/10
74	Communication	Sat 02/01/10	Sat 26/06/10
75	Photography	Sat 02/01/10	Sat 26/06/10
76	Video	Thu 27/05/10	Sat 26/06/10
77	Team Spec Sheet	Thu 27/05/10	Thu 27/05/10
78	Competition	Thu 17/06/10	Sat 26/06/10

Figure 24. Gantt chart.

13. ACKNOWLEDGEMENTS

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

- AMEC (financial assistance)
- Exxon Mobil (financial assistance)
- Focal Technologies (Moog) (donation of multiplexer for fiber-optics)
- GRI Simulations Inc. (financial assistance)
- Husky Energy (financial assistance)
- Imprint Specialty Promotions (donation of polo shirts)
- Inuktun Inc. (donation of thrusters)
- Keller America (donation of pressure transducer)
- Leoni Elocab (donation of custom-built tether)
- MATE Center (for providing this opportunity)
- Marine Institute (financial assistance and use of facilities)
- Memorial University Department of Science (financial assistance)
- Memorial University Faculty of Engineering (financial assistance)
- O'Donel High School (use of facilities and equipment)
- Pangeo Subsea (financial assistance)
- Province of Newfoundland and Labrador (financial assistance)
- SeaMor Marine (donation of cowlings and props)
- Sensor Technologies Ltd. (donation of hydrophones)
- SubConn (donation of connectors)
- Suncor Energy (financial assistance)
- 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, and Dwight Howse - for donating so much of their time and energy to this project.

APPENDIX A - FLOW ANALYSIS

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 0.25 / 0.5 / 1 m/s

• Heave up at 0.25 / 0.5 / 1 m/s

• Heave down at 0.25 / 0.5 / 1 m/s

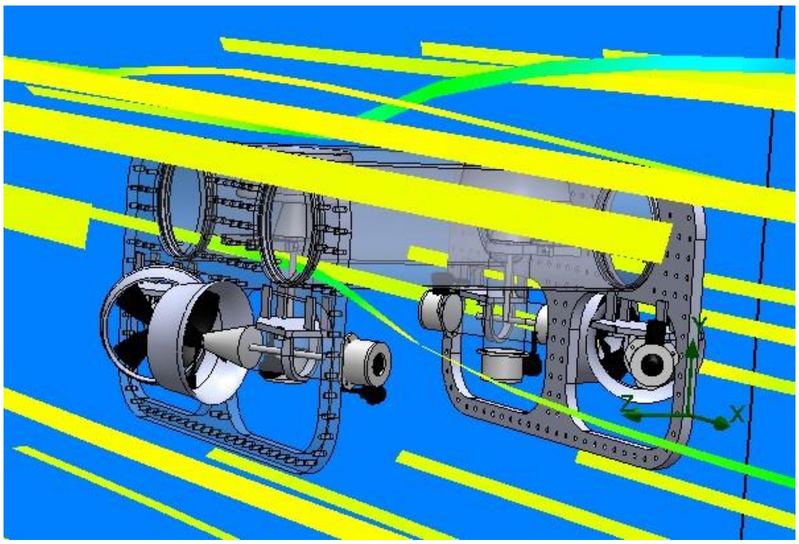


Figure A1. Flow trajectory of fluid particles as the ROV surges forward at 0.25 m/s.

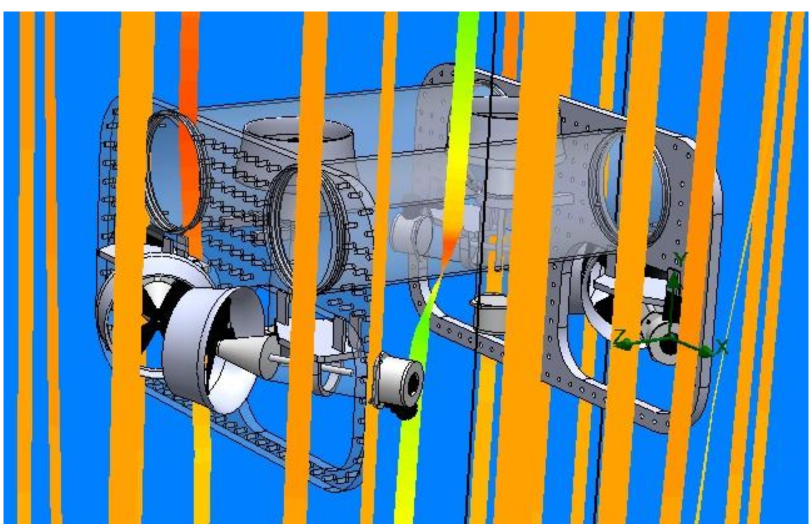


Figure A2. Flow trajectory of the fluid particles as the ROV heaves up at 0.25 m/s.

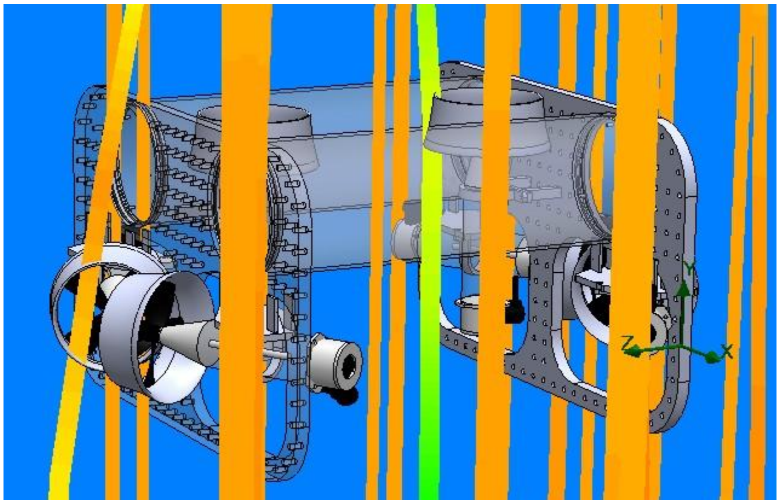


Figure A3. Flow trajectory of the fluid particles as the ROV heaves down at 0.25 m/s.

The following table and graph display 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**	1.265	1.268	1.257	1.280
Heave Up	**0.25 m/s**	-3.182	-3.184	-3.169	-3.222
Heave Down	**0.25 m/s**	2.653	2.645	2.655	2.634

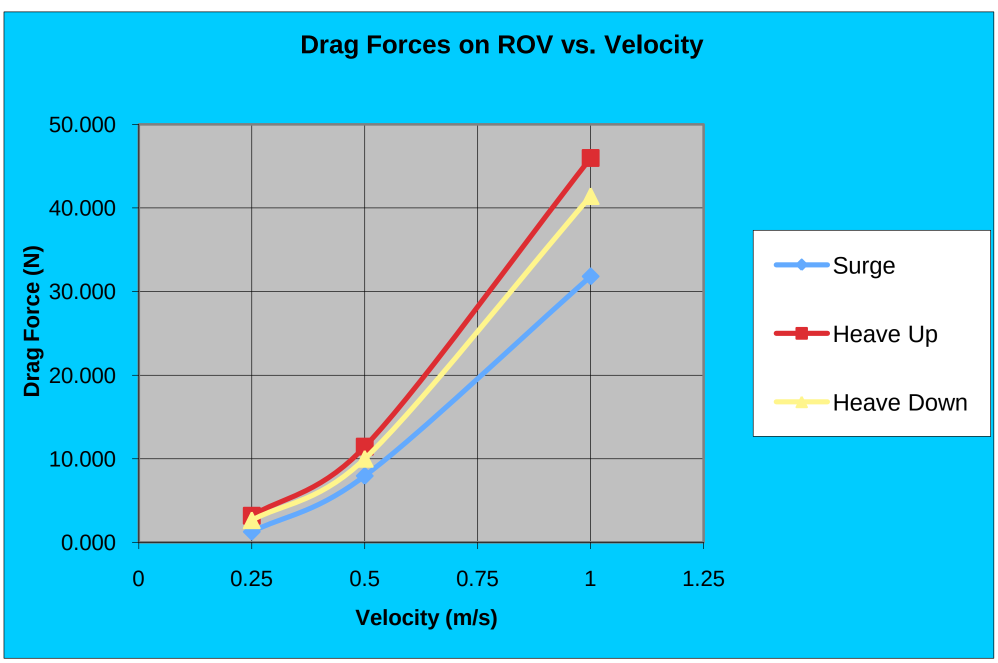


Figure A4: Forces on ROV in motion simulated at 0.25m/s, 0.5m/s and 1m/s.

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 1.265 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:

$$c_d = \frac{2\vec{F}_d}{\rho \vec{v}^2 A},$$

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

Front: 0.116m^2

Top: 0.237m^2

<u>Surge at 0.25 m/s</u>: C_d= 0.350

<u>Heave Up at 0.25 m/s</u>: C_d = 0.880

<u>Heave Down at 0.25 m/s</u>: C_d = 0.733

APPENDIX B - PROGRAMMING FLOWCHART

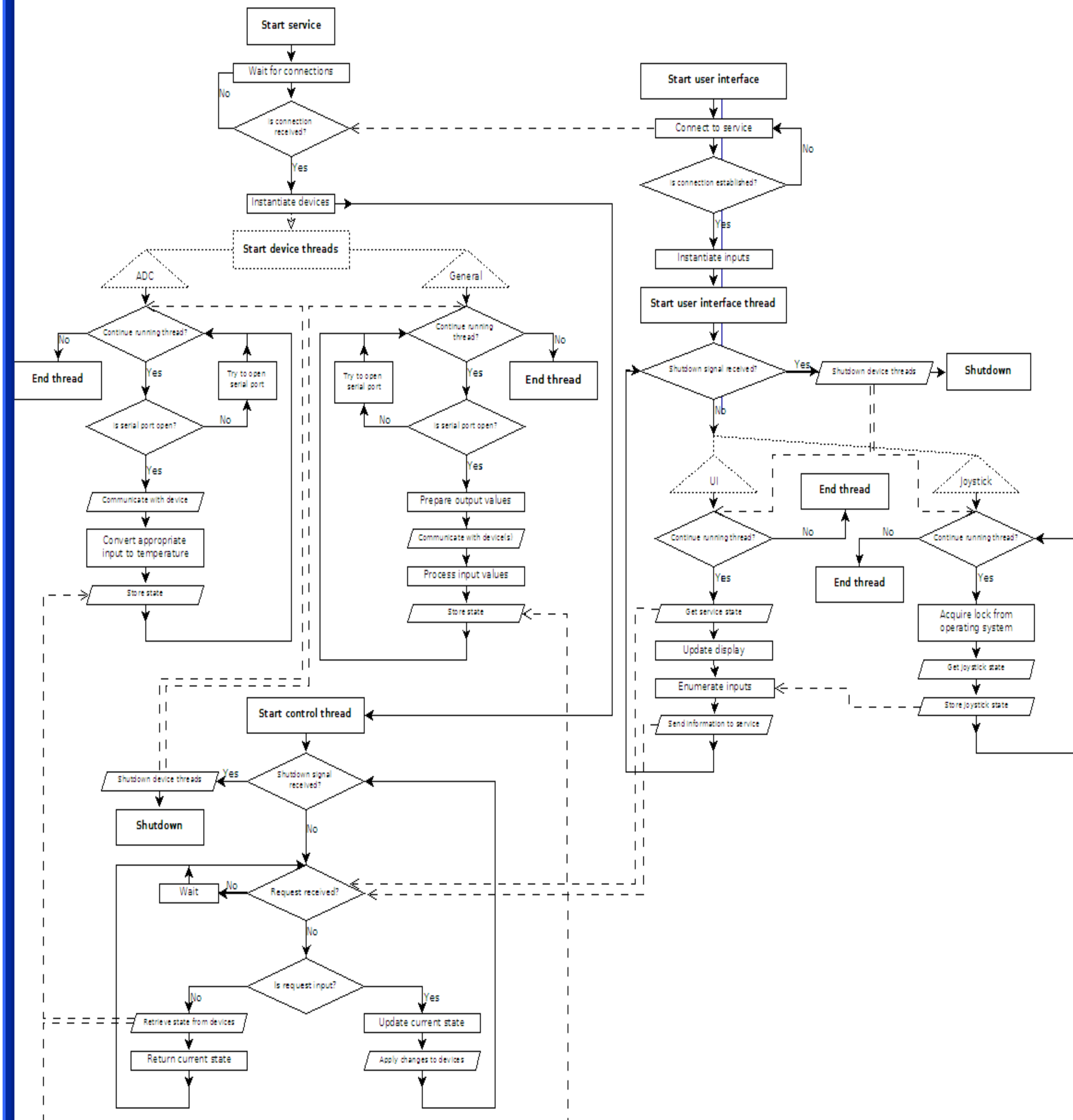


Figure B1. Programming flowchart.