Eastern Edge Robotics

Memorial University of Newfoundland and Labrador, Canada

Technical Report

MATE International ROV Competition 2011, Explorer Class

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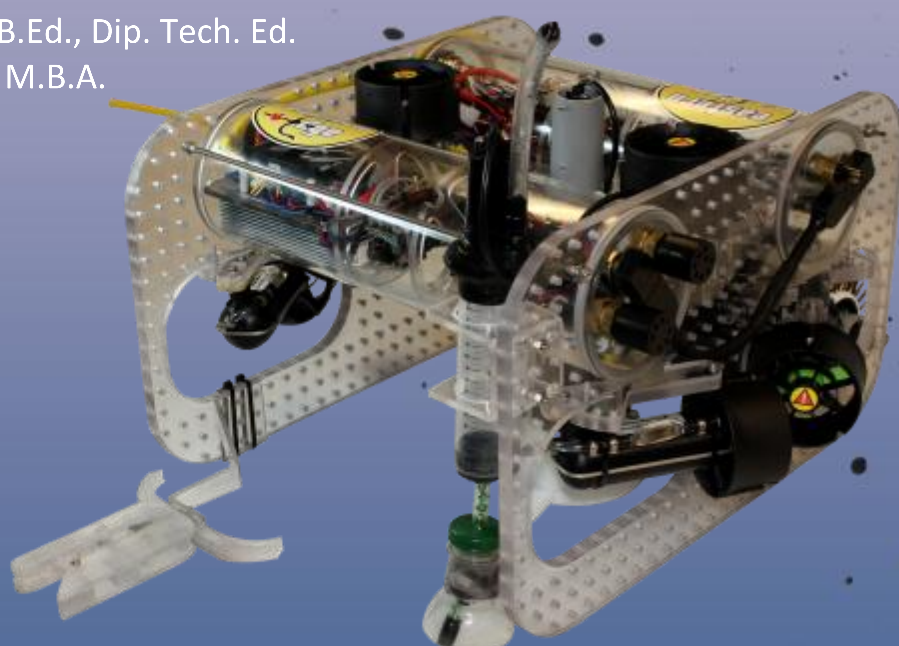

ROV ATLANTIC BLUE

ABSTRACT

Eastern Edge Robotics provides effective and quality based remotely operated vehicle (ROV) technical solutions for subsea operations. This technical report is a response to the client, Marine Advance Technology Education (MATE) Center, request for a specialized ROV system for oil spill mitigation.

The ROV *Atlantic Blue* was designed by Eastern Edge Robotics to perform specifications relevant to an oil spill response training mission as outlined by the 2011 MATE Competition. Specifically, this demanded the design and manufacture of a system capable of: removing a riser pipe, capping an oil well, collecting biological and water samples, and measuring depth. To meet this challenge *Atlantic Blue* has a chassis made of paired support skids and electronics tubes, and integrates six thrusters and three cameras. Also incorporated are four payload tools: a dual hook mechanism for removing the riser pipe, a wellhead cap, a water sampler, and a rotating brush and collection net for biological sampling. A pressure transducer was also integrated into the electronics for depth measurement. The control system, programmed in C#, is based on a client server model**.** A custom tether connects the onboard electronics system to the topsides electronics, which consists of an embedded computer system controlled by a joystick. A major innovation this year was the adoption of brushless motors.

During the process of manufacturing *Atlantic Blue,* company members learned the value of an interdisciplinary team, as the academic diversity allowed for creative, integrated problem solving. The manufacturing process and competition attendance cost approximately $40,000 including the value of donated materials.

Figure 1. Eastern Edge Robotics Team 2011

***back row** (left to right): Scott Follet, Petros Mathiodakis, Jon Watson, Evan Rice, Justin Higdon, Darren Price, Dan Rya,; Andrew Furneaux, Dave Humphries; **front**: Dave Hornell, Joanne Harris, Peter Seifert, Jacob Parsons, Suyen Oldford, Bethany Randell*

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1. BUDGET AND FINANCIAL STATEMENT

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

ITEM	DONATIONS ($CAD)	EXPENDITURES ($CAD)
Electronics cans (on ROV)		450.00
Electronics (topsides)		2,340.00
Hardware		350.00
SeaBotix™ thrusters (6 x $ 1500)		9,000.00
Fiber-optic tether - Leoni Elocab	1800.00	
Cameras (3 x $180)		540.00
Data Acquisition Module		150.00
Servo controller boards		120.00
Fiber-optic interface board – Focal Technologies™ - Moog	3500.00	
Lexan™ polycarbonate sheet		750.00
Misc. electronics components		180.00
Pressure sensor – Keller America	575.00	
Digital compass		325.00
SubConn connectors	450.00	
Group airfare (24 people x $765)		10,710.00
Accommodations, meals, ground transportation		8,500.00
Team Shirts		180.00
TOTAL	$6,325.00	$33,595.00

Table 2: Contributions to Eastern Edge Robotics.

CONTRIBUTORS	VALUE ($CAD)
Faculty of Engineering, Memorial University	5,000.00
Marine Institute	5,000.00
Faculty of Science, Memorial University	2000,00
Government/Industry Contributions	20,000.00
Student Contributions	3,600.00
Donated materials	6,325.00
TOTAL	$41,925.00

The total value of contributions received by Eastern Edge Robotics was $41,925.00, while the total value of materials and travel was $39,920.00. The monetary difference of $2005.00 is a contribution for future years.

2. DESIGN RATIONALE

Atlantic Blue was designed for use in oil spill mitigation; specifically, performing the tasks outlined by the client. This required the development of a ROV that efficiently balanced speed, stability, maneuverability, and vision capabilities within a compact frame.

Other design challenges include:

- Obstacle and line avoidance
- Precision movement and maintaining position
- Performance of a variety of different procedures that require dexterous manipulation

Consequently, the design rationale focused on:

- An ROV design which was compact and streamlined, with minimal protrusions
- Proportional movement control to permit precision movements
- Bidirectional capabilities to facilitate flexibility in attachment and effective viewing of payload tools
- 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 *Atlantic Blue* was designed to support a bi-directional ROV (*Figures 2 & 3)*. This was facilitated through the use of SolidWorks™ 3-D CAD. The chassis is comprised of two major symmetrically paired structural components: skids and tubes. The skids support two top positioned lateral tubes, which are placed in compression for lateral strength by six stainless steel truss rods. The skids are constructed from 1.27cm [1/2”] Lexan™ polycarbonate, and are drilled with a 2cm [3/16”] grid pattern of holes. This design feature creates a functionally adaptable chassis; it offers flexibility in the attachment and rearrangement of tools and thrusters. The two optically clear acrylic tubes have a 12.7cm [5”] outside diameter, and they are sealed by O-rings incorporated in 1.27cm [1/2”] caps located at each end. They have been successfully pressure tested at 2 atmospheres in the Marine Institute pressure vessel. These tubes act as the electronics cans, housing the motor and electronic components. They also provide buoyancy to the vehicle and their top location allows the thrusters, the heaviest component of the vehicle, to be attached low on the chassis for increased vehicle stability. A flow analysis of the chassis may be found in Appendix A.

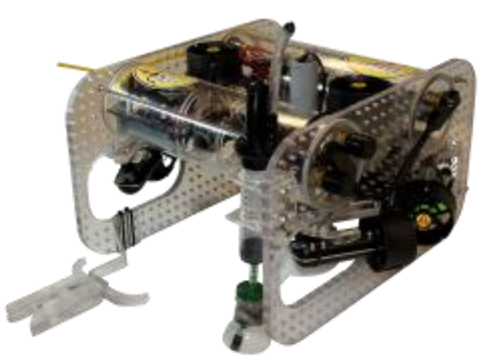

Figure 2. Atlantic Blue chassis.

Figure 3. Solidworks diagram of Atlantic Blue.

2.2 Propulsion

Figure 4. SeaBotix™ thruster.

Atlantic Blue is driven by six 280 watt SeaBotix™ HPDC1502 brushless thrusters, purchased from the manufacturer. The thrusters are rated in excess of 1000m, and are pressure compensated using a manufacturer–supplied liquid. They have SeaBotix™ proprietary 4 pin connectors accommodated by custom molded wiring harnesses. They have embedded microcontrollers which communicate using an Inter-Integrated Circuit (I2C) bus. The primary function of the microcontrollers is to control the speed of the motors by varying the rotating magnetic fields surrounding the armature of the motor. They also provide feedback from the thrusters through the use of included sensors. The thrusters are configured to provide the ROV with five degrees of freedom (forward/backward, up/down, left/right, roll and yaw). Each skid of the chassis supports one vertical thruster that is centrally mounted and two horizontal thrusters that are mounted at 30° from the longitudinal direction.

2.3 Camera

Figure 5. Super Circuits camera.

Atlantic Blue is equipped with 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. One camera is located in the center of each of the electronics cans. The cameras are tilted using servo motors to provide a 360° field of view in the vertical plane. The ROV is also equipped with a Crystal Cam high resolution (400 TVL), low light (1.0 Lux), 0.64cm [1/4”] color CCD camera. It is externally mounted on the chassis, opposite the wellhead cap. This provides an unobstructed view of the cap and release mechanism during mission execution.

2.4 Safety Features and Precautions

Safety is a priority for Eastern Edge Robotics. This encompasses not only system specific safety features, but also personnel safety training for both fabrication and operational procedures. In creating *Atlantic Blue*, mentors provided the company with workshop safety training for shop operations, procedures, and tool use.

***Atlantic Blue*'s safety features include:**

- Circuit protection and kill switch for emergency stoppage
- Fully shrouded thrusters to prevent injury
- Rounding and removal of all sharp edges
- Temperature and humidity sensors inside the onboard containments to forewarn incidents of overheating or leakage
- Secure tether attachment and strain relief to avoid breakage or damage
- Warning signs located near moving components and electrical hazards

Personnel safety precautions for vehicle operation include:

- Training and practice in safety protocols
- Careful stowage, deployment, and management of the tether during mission operations
- A power-off protocol for the pre-dive check operations, except when 'ALL CLEAR' is designated by the deck manager
- Life jackets requirement for all deck crew during testing

3. CONTROL SYSTEM

The control system for *Atlantic Blue* was built by Eastern Edge Robotics. Written in C#, it runs as a Windows Communication Framework service hosted as a Windows service. It is an improvement over control systems used by the company in the past because it enforces a strict three-tier object oriented architecture design (device libraries, application logic, and user interface). 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. This allows for an easily modifiable and customizable system in which library objects are considered atomic. Currently, the software has a device library (pressure sensor, accelerometer, etc.) and libraries for logic (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.

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 directly 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 when performing floating-point arithmetic.

The abstraction of objects, making them universal for implementation of the ROV, allows the software to be easily modified to operate for a different vehicle system.

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 user interface (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 the software as a Windows service means that it is always resident. However, this also means that the previous paradigm of "set and forget" for thruster control is no longer appropriate, as it creates a safety concern. If the thrusters are turned on and the client loses connection to the ROV, then the thrusters would still continue to operate, meaning that the ROV could not be stopped. To fix this the control system was designed to use heartbeat signals with outputs. If the heartbeat is not seen in a given timeframe the control will run a default signal to 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 as needed. The GUI is split into six windows: main operations, 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, which means 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.

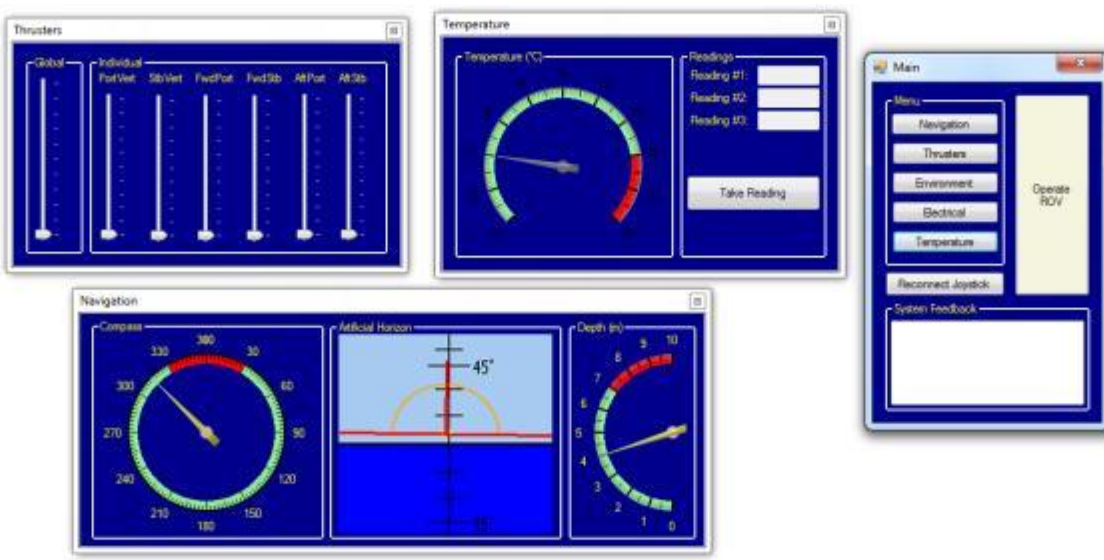

Figure 6. Graphical User Interface (GUI).

3.4 Code Management

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

In previous years the company encountered problems managing the digital files, especially source code. Frequently, files were e-mailed and deposited in online repositories to be distributed to those who needed them. However, delays occurred in attempting to track them down. This year subversion (SVN) permitted the establishment of 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 was used to indicate stable versions of the code.

Eastern Edge Robotics was fortunate enough to gain access to the SVN server at Memorial University's Computer Science department, which was an optimal choice because it is a dedicated server that is reliably available at all times. Due to the company's association with Memorial, it will be possible to pass the repository on to new members when 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 payload control can. See Figures 8 and 9 for the electrical schematics of these components.

4.1 Topside Control Unit

Figure 7. Topside control unit.

The topside control unit (*Figure 7*) provides electrical protection as well as communication to the ROV. From the main 48 volt DC input power is routed through a 20 amp circuit breaker, through 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, a 100GB solid-state drive (SSD), and a 500GB hard disk drive (HDD). This provides plenty of control and video processing capability for the ROV system. Additionally, 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. Also, a B&B Electronics 8-port RS-232/422/485 serial interface card is used for data communications to the ROV. Both of these cards are connected to the topsides Model 907 video/data multiplexer unit from Focal Technologies™. This unit allows for communication to the ROV over a single fiber strand. All of the six serial data channels (2x RS-485, 4x RS-232) on the multiplexer are connected to the serial interface card and the three video channels are connected to the video capture card. In addition, the topside computer is powered from a standard 120 volt ATX power supply and all communications to the ROV are though fiber optics. This electrically isolates the topsides control unit from the ROV unit, providing additional safety for both the operators and the sensitive electronics in the topsides computer.

POWER DISTRIBUTION SCHEMATIC

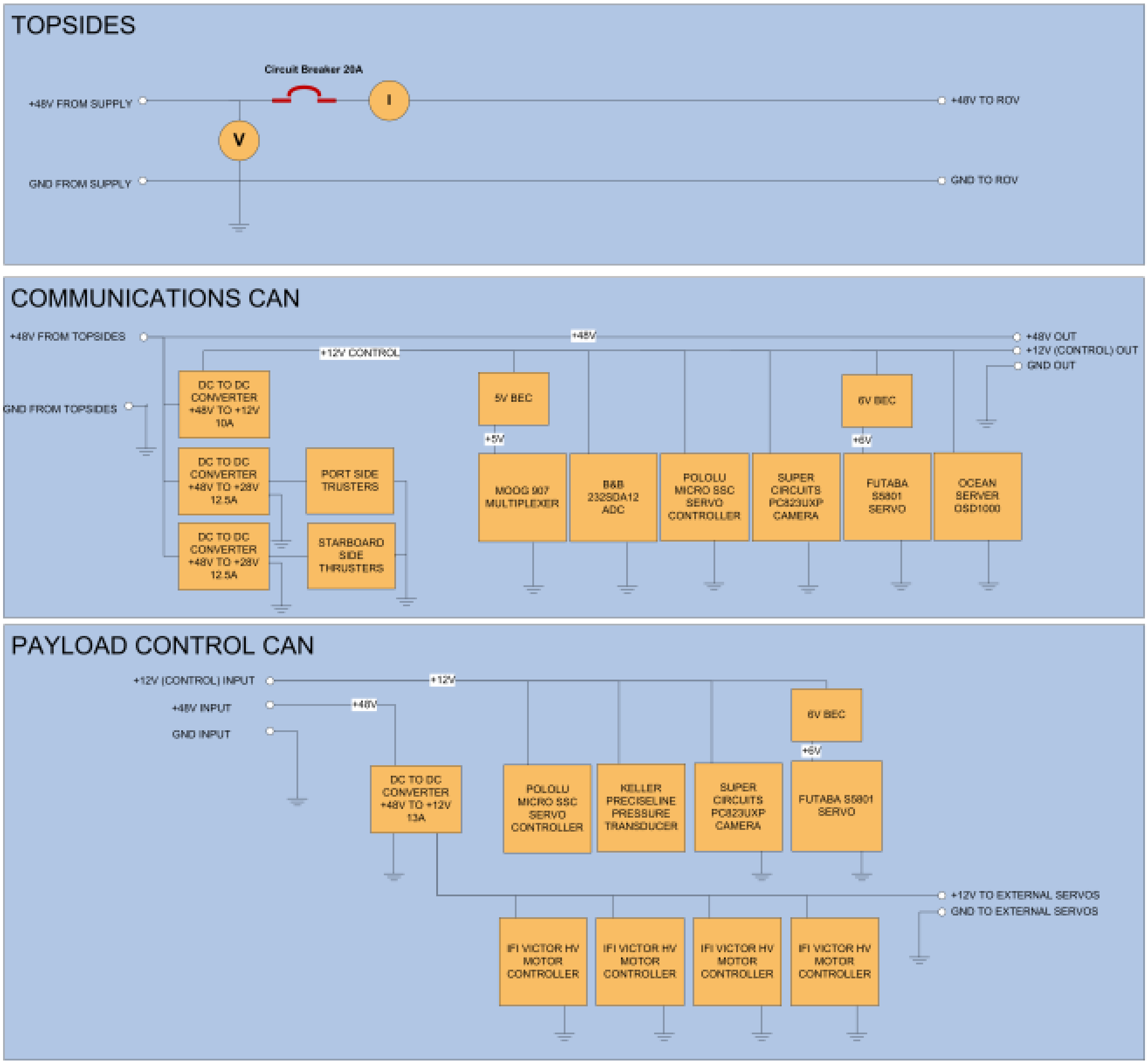

Figure 8. Electrical schematic of power distribution.

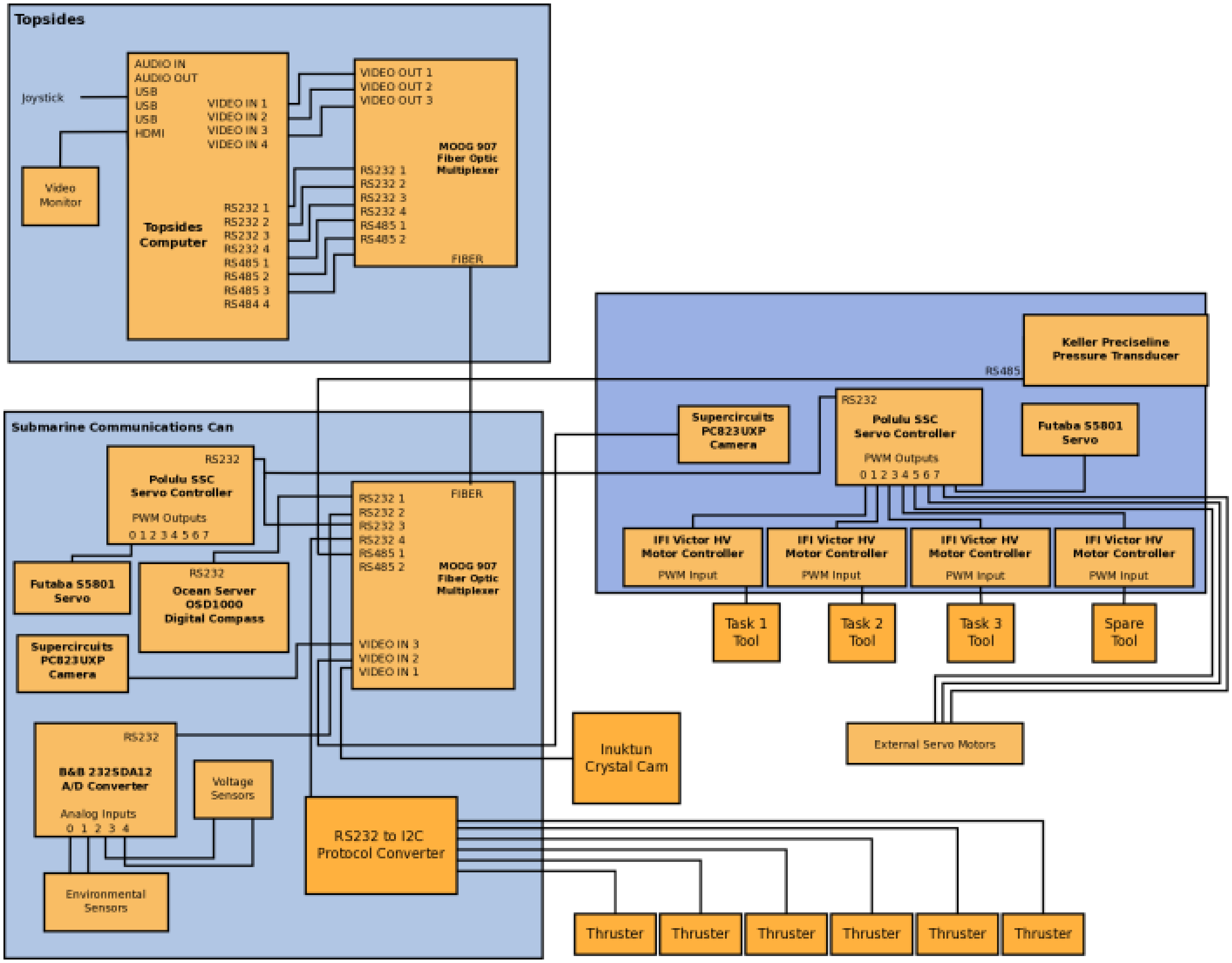

Figure 9. Signal flow diagram.

4.2 Tether

Figure 10. Custom-designed tether.

A custom tether was donated to Eastern Edge Robotics by Leoni Elocab Inc. of Kitchener, Ontario, Canada (*Figure 10*). It was designed to be neutrally buoyant in fresh water, and the outer jacket has a low drag polyurethane coating. 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 only for use in the event of failure or damage to the primary strand. 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 the tether is carried into the communications can by a brass penetrator, custom-machined by Eastern Edge Robotics. It is terminated electrically with ring terminals to the power distribution lugs, and optically with two ST connectors.

4.3 Submarine Communications Can

The main onboard electronics, which provide communications to the surface and control the thrusters, are located in a clear acrylic waterproof tube (*Figure 11*). The tube measures 12.7cm [5”] outside diameter x 35.0cm [16”] long, and has a custom-machined polycarbonate cap at each end. Subconn® multi-pin bulkhead connectors provide an electrical connection to the outside and payload can (see Section 4.4). Inside the can, multiple devices provide communications to the surface, data acquisition, and thruster control. Also, two 28 volt output and one 12 volt output DC-DC converters in the can drop the 48 volt main rail input down to lower voltages that supply the thrusters and 12 volt rail. The converters are rated for an input voltage of up to 75 volts, and 12.5 and 10 amps, respectively.

The remote unit of the Model 907 multiplexer transmits the serial data and the analog video 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 to 5 volt range for each of its 11 inputs. To ensure proper voltages in the communications can, power supply voltages are sampled through voltage divider circuits. A Microchip™ TC1047A sensor, capable of recording temperatures from -40°C to +125°C, monitors the internal temperature to ensure that the contained components are not overheating. A Humiriel™ HTM1735 sensor, capable of recording humidity levels from 10% to 95% rH, monitors the relative humidity inside the can in order to inform the operator of condensation buildup or water leakage.

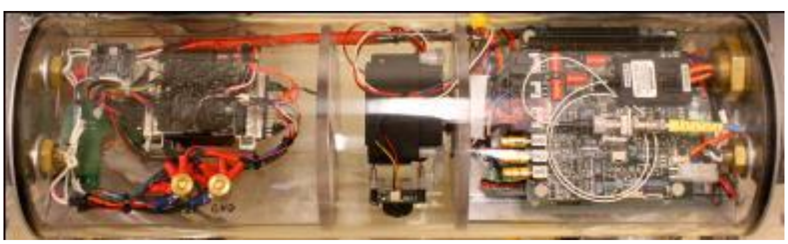

Figure 11. Submarine communications can.

To communicate with the embedded microcontrollers of the thrusters, an RS-232 to I2C bus converter is used. This was custom designed by the team and is based on a PIC18F1320 microcontroller. It connects to the multiplexer over a RS-232 bus and provides six individual I2C busses which connect to the six thrusters.

Another sensor inside the can is an Ocean Server™ OS-1000 digital compass, which communicates over an RS-232 bus. It provides the ROV with a heading 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 communications 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% 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. In software, this pressure reading is converted into depth, taking into account the configurable water density and current atmospheric pressure. This device is used to provide a depth measurement in Task 3, and as feedback to an auto-depth function featured in the control system. The pressure transducer also measures 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 Payload Control Can

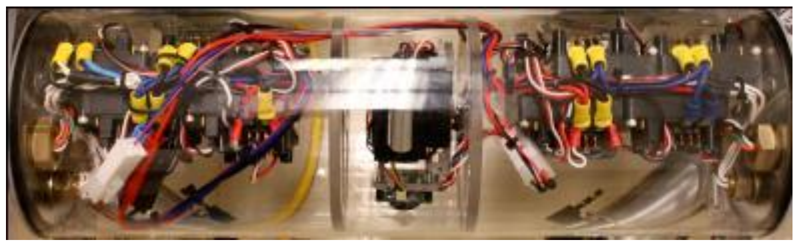

Figure 12. Submarine payload control can.

The submarine payload control electronics are housed in a can of the same design and dimensions as the communications electronics can (*Figure 12*). It is linked to the vehicle control can using a single 9-pin connector, which supplies both power and communications. The can controls all payload tooling onboard the ROV, and has been designed to accommodate current and future tooling. A DC-DC converter is used to reduce the main rail voltage to 12 volts, with the ability to provide 13 amps of current to the onboard tooling. One Pololu™ 8-channel servo controller receives a RS-232 connection from the vehicle control can which outputs eight pulse width modulated signals. Four of these signals are fed to IFI Robotics Victor™ HV pulse width modulators (PWMs), which are in turn connected to the tooling motors. Three more of these signals can be fed to external servo motors through the external servo connector, and one signal is fed to the servo motor that tilts the second onboard camera.

5. PAYLOAD TOOLS

5.1 Task 1: Remove the damaged riser pipe

Figure 13. Dual hook

Task 1 requires *Atlantic Blue* to transport and attach a line to the U-bolt on the damaged riser pipe. Once this is completed it is necessary to simulate the cutting of the riser pipe, which may then be lifted away from the wellhead and base via the attached line. To accomplish this task, a dual-hook mechanism (*Figure 13)* consisting of two distinct components was created. The first component is an integrated gated hook with an attached line, while the second is an open hook. Structurally, the gated hook consists of a body and a gate. The body was crafted from two symmetrically paired U-shaped pieces of Lexan™ (measuring 12.0cm x 7.0cm x 0.5cm), and separated by a 1.3cm gap. The gate is formed by a spring-loaded toggle. Lexan™ levers are placed transversely across the mechanism between the two main body components. When the U-Bolt travels through the gate it strikes the first of the two levers, which acts as a pressure plate and applies force to the end of a second strip. The force from this collision releases the gated hook from the Lexan™ bracket.

Once the gated hook has been released a two-pronged Lexan™ open hook is exposed. This hook is used to simulate the cutting process by catching the ring on the Velcro strip and using the thrust of the ROV to pull it away. The entire mechanism is connected to the ROV in position via a Lexan bracket.

5.2 Task 2: Cap the Oil Well

With the damaged riser pipe cut and removed, a cap must then be fitted onto the wellhead to stop the emerging flow of oil. To complete this task Eastern Edge Robotics fabricated a custom wellhead cap. (*Figure 14)* The cap consists of three major components: the housing, the locking mechanism, and the plugging mechanism. The housing, which fits over the wellhead, is a high density polyethylene (HDPE) base, outside diameter of 12.8cm [5”], attached to a PVC reducer with a 4.8cm [1.9”] top outside diameter and 8.9cm [3.5”] bottom outside diameter. The locking mechanism, which consists of three pieces of HDPE and an elastic band, is contained within the base of the housing. As the cap is lowered onto the pipe the beveled edges of the locking mechanism act as a guide. It then expands over the top lip of the riser pipefitting. The elastic band restores the shape of the fitting and prevents it from moving further down the pipe. The top of the reducer contains a piece of 1.4cm [1/2”] thick HDPE that is surrounded by a ring of ABS for a total outside diameter of 4.8cm [1.9”]. Embedded in the HDPE is a threaded rod, at the bottom of which is a 5cm [2”] diameter rubber plug. They are connected via a bearing to ensure that the plug does not rotate as the rod progresses through the threaded nut. The advancing rod forces the plug into the open well head, cutting off the flow of oil. A hex attachment at the top of the rod fits into a planetary gearhead with a 9:2 gear ratio, powered by a 200GPH bilge pump motor. The gear head and motor are joined inside a 16.6cm [6.5”] long x 3.4cm [1.3”] inner diameter conduit housing that is flared to a 5cm [2”] inner diameter at one end.

Figure 14. Oil Well Cap

Magnets mount the cap to the ROV. The application of vertical thrust is all that is required to detach from the device. To remove it from the well head a diver must manually back the plug out of the well, pull the tabs of the locking mechanism (or manually spread the beveled edges), and remove the entire cap.

5.3 Task 3: Collect water samples and measure depth

For the task of measuring depth and collecting water samples Eastern Edge Robotics incorporated a pressure transducer into its electronics system and designed a custom sampling mechanism. (*Figure 15)* This task requires *Atlantic Blue* to collect a saline water sample from a container with a 1.9cm [3/4”] pipe opening. A Preciseline™ pressure transducer from Keller America (see Section 4.3) is used to measure water depth and determine the correct sample site.

The apparatus used by *Atlantic Blue* to collect the water sample consists of three major components: a bilge pump, a plastic syringe, and a vinyl tube. The 12 volt 200GPH bilge pump is mounted on top of the plastic syringe, which has a sampling capacity of approximately 140ml and measures 4.1cm [1.6"] outside diameter x 14cm [5.5"] length. Fitted to the tip of the syringe is a 0.6cm [1/4"] outside diameter vinyl tube, which is equipped with a plastic sliding guide and foam seal. The distal end of the tube is covered with mesh and it is filled with small beads to decrease the volume of compressible air.

Figure 15. Water sample collector

To obtain the sample the syringe must first be filled with water before the ROV is deployed. The tube may then be maneuvered into the container with the aid of a clear plastic guide. The pump is then turned on and the water is pulled out of the syringe. This creates a pressure differential between the inside of the syringe and the tube, causing the depressed plunger cap to rise and draw the sample. The apparatus is mounted to the chassis of the ROV with a custom C-shaped Lexan™ bracket. The bracket is equipped with two holes that permit the water sampler to slide up when the ROV must make contact with the subsea surface for biological sampling.

5.4 Task 4: Collect Biological Samples

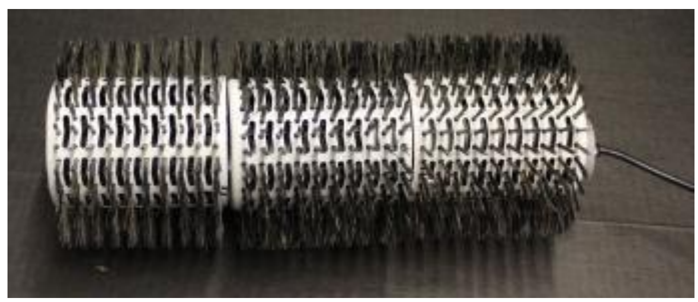

Figure 16. Brush biological sample collector.

Task 4 involves the collection of three samples each of three different biological specimens located on the subsea surface. To complete this mission several different tools were designed and prototyped. Prototypes included a sweeping-broom action collector, and a tool similar in appearance to an upside-down drawer with rack and pinion gear. The final tool designed for this task utilizes a rotating brush and a collection net mounted on the ROV (*Figure 16*). A 200GPH bilge-pump motor spins the brush via a planetary gear head with a 9:2 gear ratio. The brush is made from three 5.9cm [2.3"] internal diameter cylindrical hairbrushes. They are connected via two custom machined 1.3cm [1/2"] x 5.8cm [2.3"] outside diameter Lexan™ disks, resulting in a total length of 32.4cm [12.7"]. The disks provide a solid platform for the axle, and also include holes for water to pass through, reducing drag and stress on the motor. This tool is mounted at the bottom edge of the ROV via Lexan brackets attached to both sides of the chassis. These brackets were custom machined with a vertical track to allow the brush to lie on the seafloor and rise over the larger samples. This function provides the tool the flexibility to capture all specimens. Once the pilot has located the samples, the motion of the brush pulls the specimens into the collection net, securing them to return to the surface.

6. CHALLENGES

This year's mission tasks provided a unique and educational set of challenges that consistently demanded dynamic problem-solving skills. Chief among these challenges was the development of a simple and effective wellhead cap device. The initial prototype was built from readily available plumbing equipment, including hose clamps, ball valves, and rubber reducers. Following preliminary testing, it was determined that this design was overly complex. Additionally, it was inferred that the torque required to secure the cap was more than a single 12 volt bilge pump motor could supply. In order to remedy this, the store-bought components were replaced with parts designed and manufactured in-house. The manually actuated valve was completely eliminated in order to reduce the number of required motors from two to one. Although this resulted in a more streamlined prototype, there were still performance issues.

As testing progressed, the team decided that the wellhead cap would require further development in order to increase its efficiency and reliability. The tool was still quite unwieldy, containing a large number of HDPE brackets, and the 12 volt motor still struggled to secure the device. As such, the number of brackets was carefully reduced, ensuring that enough were kept in place to guarantee reliability. This significantly reduced the bulk of the tool without affecting its performance. In order to improve torque, the planetary gear assembly from a 12 volt drill was integrated into the motor housing. In turn, this provided another set of difficulties, the resolution of which is discussed in Section 7 Troubleshooting. The added torque coupled with the use of the gear assembly greatly augmented efficiency of the tool. Further reduction of bulk and complexity was achieved by altering the cap assembly to be mechanically jettisoned by the action of the motor. The combination of these design changes resulted in a dependable, lightweight, and efficient tool that Eastern Edge Robotics deemed appropriate to use in competition.

With respects to software, there was a significant challenge concerning code management. As mentioned previously (Section 3.4), SVN was used to manage changes to code and maintain a backup. Problematically, the network security at the company work facility made it difficult to connect to the code repository in order to download the software for development. As a result, most of the network transactions required relocation to obtain a reliable connection and complete the transfer, directly correlating to a reduction in productivity. Transferring the most recent software version from the development machines to *Atlantic Blue*'s computer required both the vehicle and the ROV computer to be moved to a location with Internet access. This lost time had a significant impact on the testing and electrical work.

7. TROUBLESHOOTING TECHNIQUES

In designing *Atlantic Blue* and the payload tools, Eastern Edge Robotics faced a major challenge in using planetary gears as a speed-reduction mechanism. The planetary gears are required to decrease the RPM of the bilge pump motors used in the operation of two payload tools, the biological sampler mechanism and the wellhead cap (Sections 5.2 & 5.3). During the process of prototype testing both tools presented very similar problems: neither mechanism was functionally reliable. This proved to be especially problematic because the root cause of the problem was not readily apparent and several correction attempts were necessary before it was concluded that the problem lay in the planetary gear set.

Eastern Edge Robotics used trial and error to overcome this challenge. Initially, it was assumed that a component of the gear set might have been slipping out of place. To counter this, the tooling mechanism was reassembled multiple times to ensure each element was assembled correctly with all gears properly meshed. When mechanism failure continued to occur, a second set of planetary gears was used to test for a potential weakness in one of the components. Ultimately, neither approach was successful in eliminating the operational inconsistency for the tools. This led to the conclusion that something in the planetary gear configuration must not be functioning as intended. Research and inspection led to the observation that in the original gearbox the outer ring gear of the planetary gear set was fixed. When the set was transferred to the bilge pump motor, the ring gear was no longer fixed in the intended arrangement, thus allowing it to freely rotate when the bilge pump was in operation. This rendered the planetary gears ineffective, negatively impacting the functionality of the tools. To rectify the problem set screws were used to hold the ring gear stationary, allowing the planetary gear set to function as intended. This proved to be an effective solution, as the tools were operational.

8. FUTURE IMPROVEMENTS

Future improvements that Eastern Edge Robotics is considering include:

i) A better tether management system, with hybrid fiber-optic slip rings and an improved launch and recovery system. The fiber-optic slip rings allow the tether to be put on a roll, eliminating tangling on the surface.

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. This multi-purpose tool would allow the team to remain with industry standards, cutting down on tool design time and increasing mission success rate.

Figure 17. Jonathan working on topsides unit.

9. LESSONS LEARNED

The tasks presented by MATE required specialized ROV technology for oil spill mitigation. This challenge required the members of the Eastern Edge Robotics to think creatively and improve upon both their technical and interpersonal skills. In developing *Atlantic Blue,* the company was able to remove two items from the 'Future Improvements' list. Specifically, advancements were made in moving to brushless thrusters with embedded controllers. These new thrusters have many notable advantages over the brushed thrusters that were used previously. One of these benefits is improved efficiency, due to the absence of energy losses caused by the friction of brushes. Also, less electronic noise is produced, reducing interference with other electrical components. Thruster maintenance has been reduced and lifetime lengthened, as there are no brushes to wear out or leave residue within the unit. These thrusters are more powerful, yet lighter and less bulky than their predecessors. Finally, the embedded controllers eliminated the need for pulse-width modulators within the electronics can, thus reducing their size and therefore the width of the ROV.

Interpersonal relations are integral to the success of Eastern Edge Robotics. Currently, the team consists of 18 team members from a variety of academic disciplines, including: computer science, ROV technical programs, archaeology, and engineering (electrical, mechanical, and ocean naval). This diversity can be both beneficial and detrimental to the company. While it is beneficial for divergent thinking during the brainstorming process, convergent thinking is required for prototype development. This can result in disagreement, which is resolved through the development of multiple design ideas. In this way, objective agreement may be reached. The knowledge disparity that exists is also a challenge, as members may not be able to fully participate in certain processes. 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.

Figure 18. Andrew working on the manipulator.

10. REFLECTIONS ON THE EXPERIENCE

"Even as a first-year university student with limited experience, I have found my experience with Eastern Edge to be a very important part of my education. Like many of my peers, I was initially unsure which program of study I wanted to pursue and was not yet comfortable with post-secondary life. Since joining the team, I have had the opportunity to work with more experienced students and industry professionals, and have learned a great deal about the opportunities available in many different fields. My time spent working with robotics has been pivotal in my decision to pursue engineering as a degree, and I feel that the chance to learn from individuals who have years of experience working in a professional, competitive environment has helped me to develop skills and knowledge I would not have gained without my involvement with Eastern Edge."

– Jacob Parsons, 1st year student, Memorial University

"Having been involved with the MATE ROV competition since high school, I have had many fond memories and have made many friends over the years. I have been involved with the design process several times and have developed my problem solving, communication and manufacturing skills immensely. The competition itself has allowed me to travel to many different locations and meet people from various parts of the world. Although I already had an idea of what I wanted to do, my experiences with the team has opened my mind to pursuing a career that involves working with ROVs. Overall, I feel that my time on the Eastern Edge Robotics team has been very rewarding and as I near the end of my final year as a member of this team, I will miss coming in to work on the ROV with the friends that I have made."

- Scott Follett, 10th year veteran Eastern Edge Robotics, ROV Technician

11. TEAMWORK

In order to organize the company and ensure that all components of the MATE Competition were completed on time, each company member was designated a specific to a task division. While all members were involved in all processes (design, construction, testing, and communications), it was possible to delegate responsibility and ensure that everything would be completed on time. To aid in this goal, a chart noting each member's areas of responsibility was made (Figure 23).

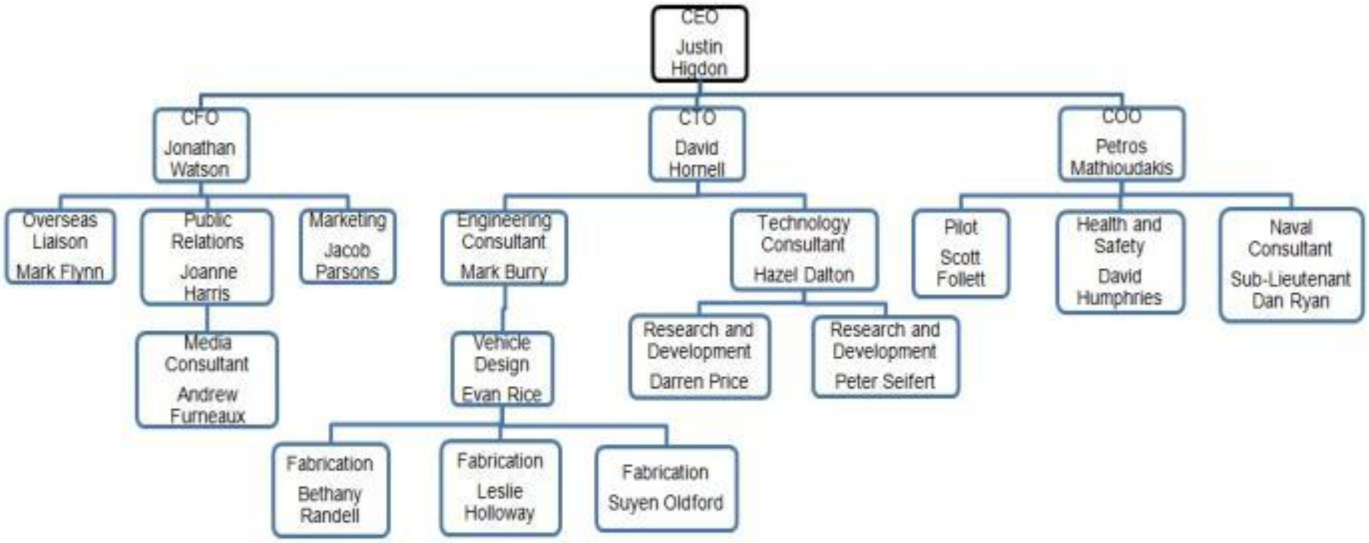

Figure 19. Team organizational chart.

To aid in the scheduling process a Gantt chart was completed at the beginning of the year (Figure 24). This helped to ensure that the ROV completed and as much time to practice before the competition as possible.

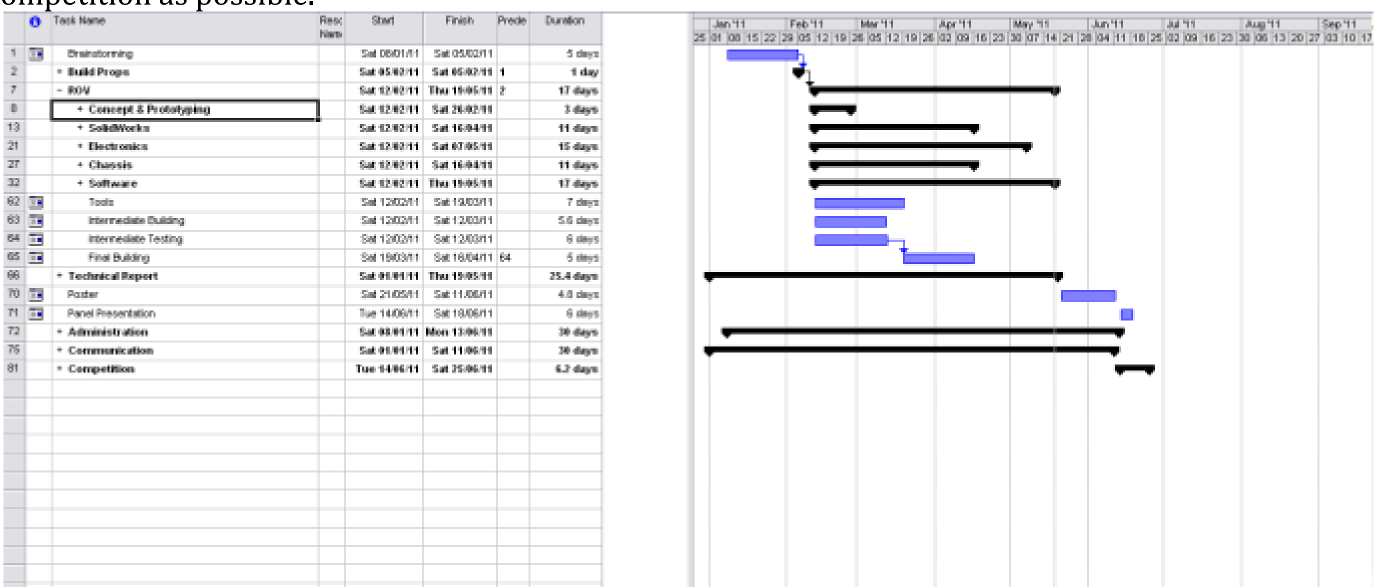

Figure 20. Gantt chart.

12. ACKNOWLEDGEMENTS

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- SubSea 7 (financial assistance)
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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

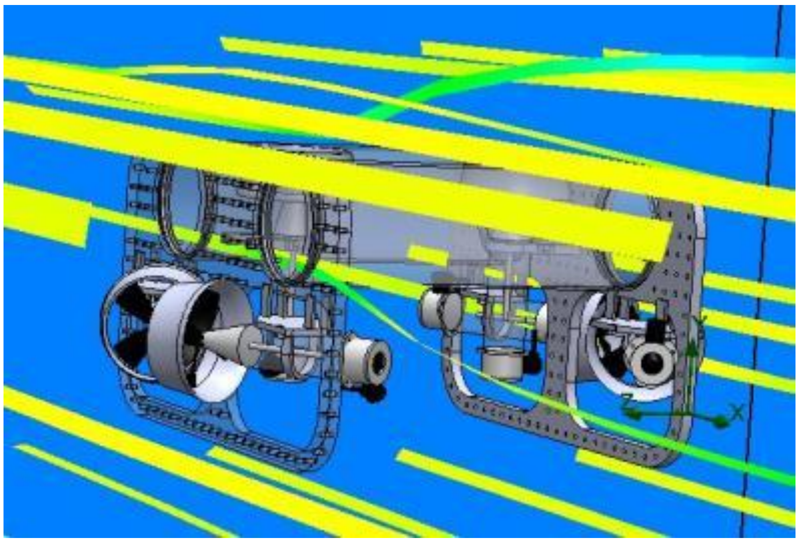

Figure A1. Flow trajectory of fluid particles as the ROV surges forward at 0.25 m/s.

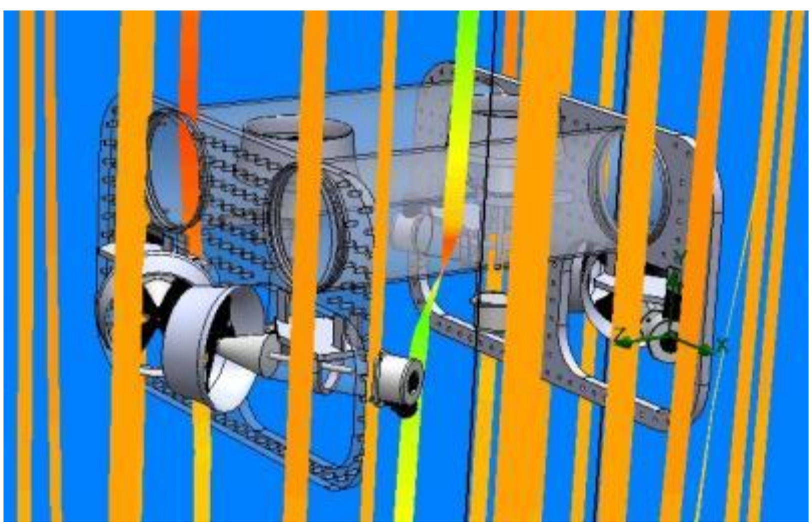

Figure A2. Flow trajectory of the fluid particles as the ROV heaves up at 0.25 m/s.

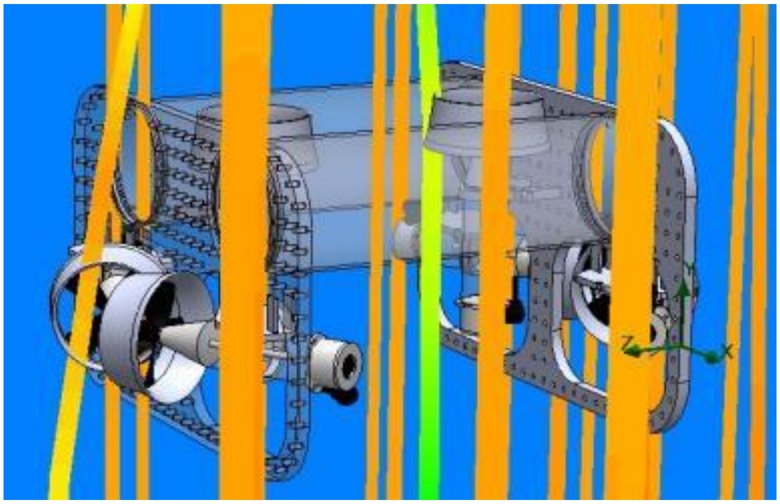

Figure A3. Flow trajectory of the fluid particles as the ROV heaves down at 0.25 m/s.

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

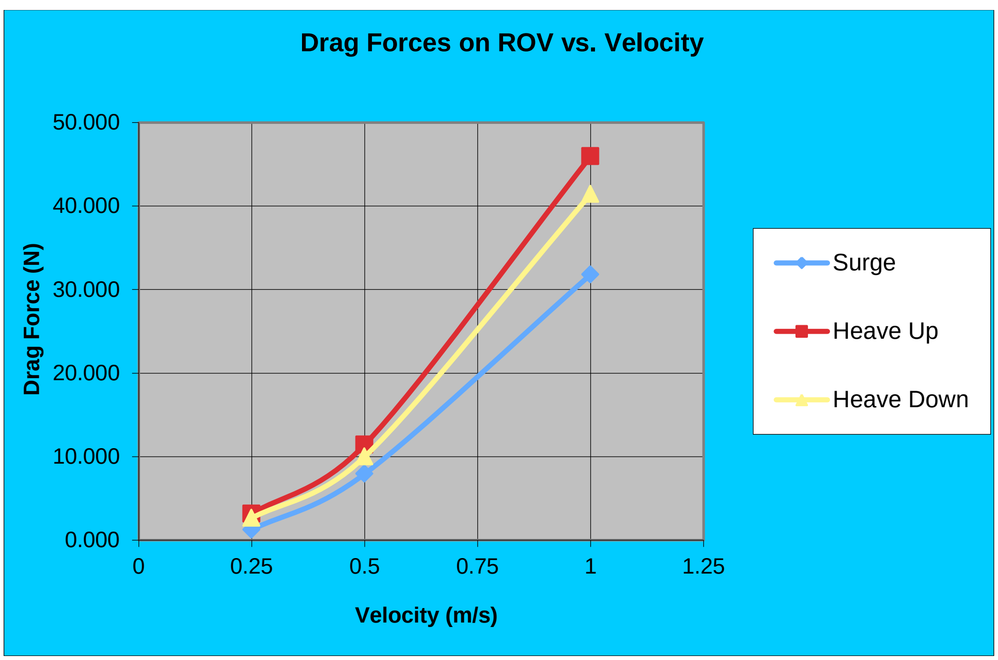

Figure A4: Forces on ROV in motion simulated at 0.25m/s, 0.5m/s and 1m/s.
The drag force is in the opposite direction to their respective motion, e.g. surge forward (positive X-direction) at velocity of 0.25 m/s exerts a force of 1.265 N in the negative X-direction.

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

$$F_D = \tfrac{1}{2}\,\rho v^2\, C_d\, A,$$

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

Surge at 0.25 m/s: C_d= 0.350

Heave Up at 0.25 m/s: C_d = 0.880

Heave Down at 0.25 m/s: C_d = 0.733

APPENDIX B - PROGRAMMING FLOWCHART

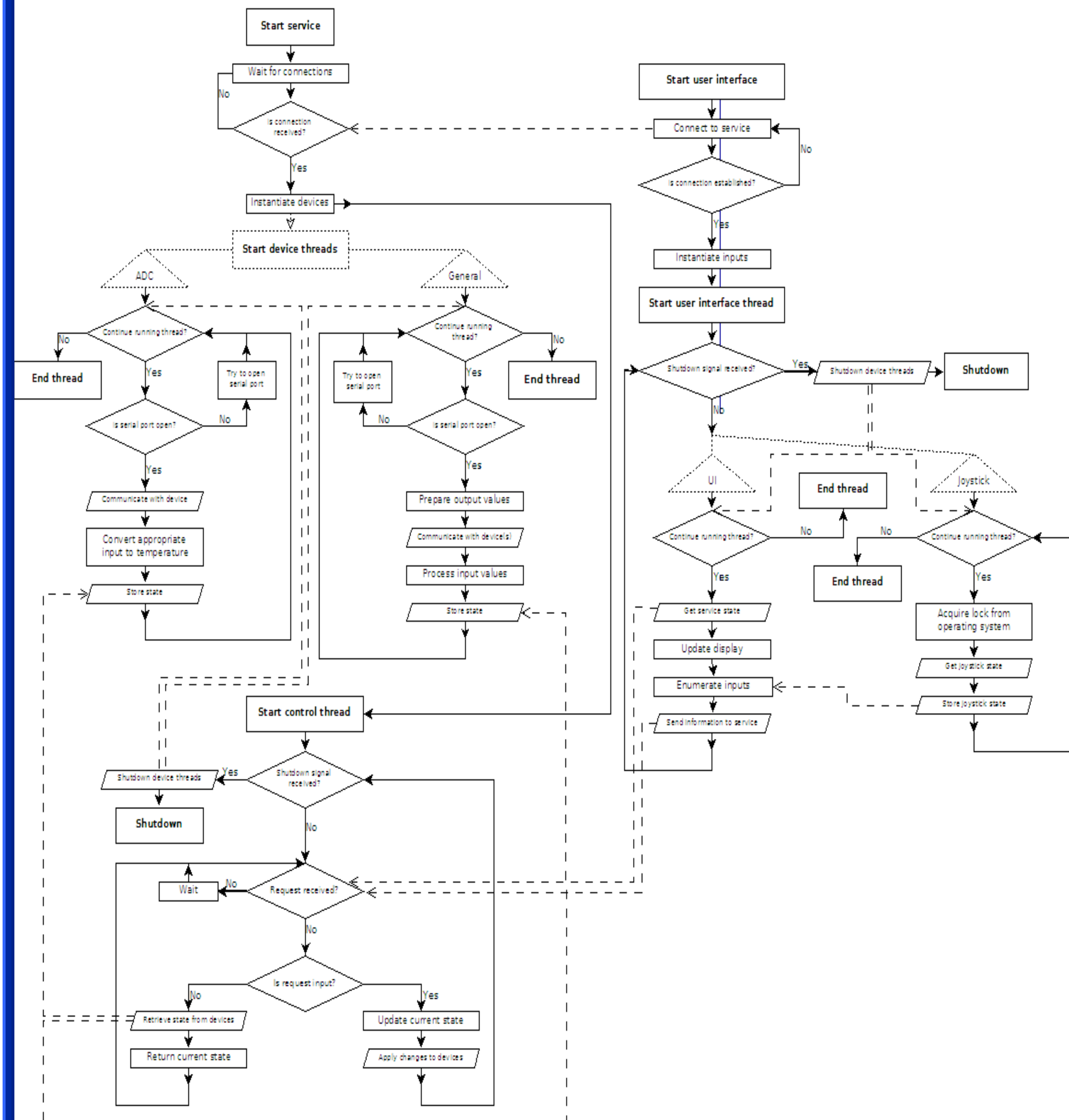

Figure B1. Programming flowchart.