eastern Edge robotics

Memorial University, St. John's, Newfoundland and Labrador
MATE International ROV Competition 2019, Explorer Class

Company Employees:

Name:	*Role/Discipline:*
Michaela Barnes	Chief Executive Officer
Stephen Chislett	Chief Financial Officer
Charity Talbot	Chief Safety Officer
Mark Belbin	Chief Technical Officer - Electrical
Nathan Hollett	Chief Technical Officer - Mechanical
Keith Sutherland	Chief Technical Officer - Software
Josh Burt	Pilot/Mechanical
Liam Gregory	Administration
David Drover	Electrical
Ogheneovo Jatto	Electrical
Patrick Whelan	Electrical
Jake Hollett	Mechanical
Keely Lullwitz	Mechanical
Paul Derail	Mechanical
Stephen Snelgrove	Mechanical
Zack Rooney	Mechanical
Andrew Troake	Software
Conquest Paul-Eboigbe	Software
Josh Kearney	Software
Julia Dawe	Software
Nana Abekah	Software
Victor Linfield	Software

Company Mentors:

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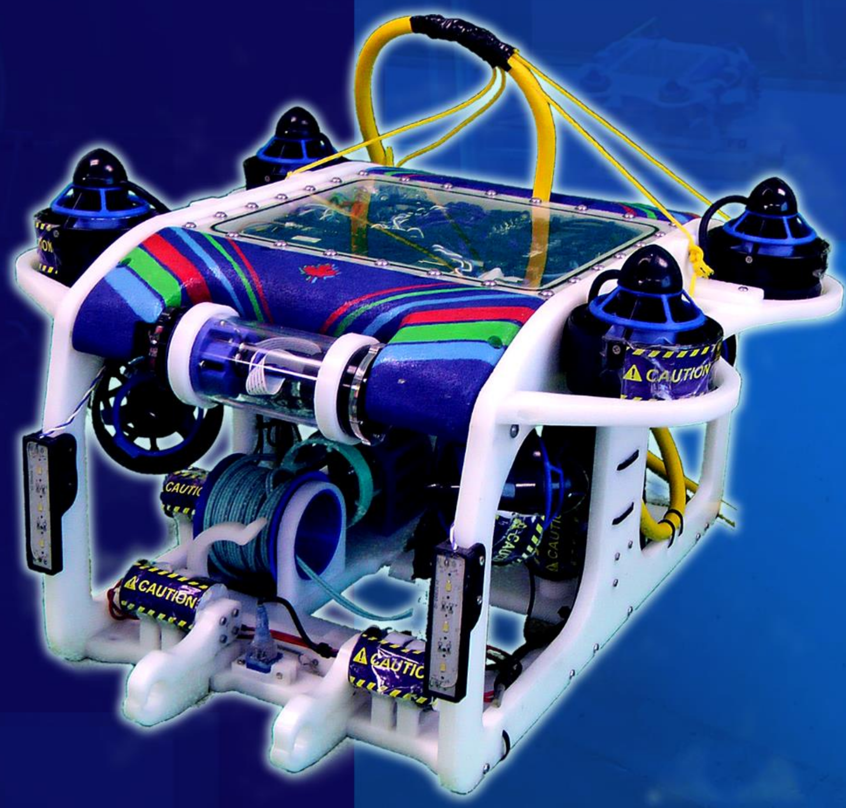
MARINE INSTITUTE

MEMORIAL UNIVERSITY



Technical Documentation

Abstract

Eastern Edge Robotics (Eastern Edge) is a diverse company, playing to the strengths of each of its employees to deliver the most successful product. Based out of the Memorial University of Newfoundland and the Marine Institute, the company is made up of 22 employees (Figure 1) from a variety of backgrounds. With 17 years of experience developing Remotely Operated Vehicles (ROVs), Eastern Edge has created several award-winning vehicles and has brought these experiences and successes forward into future developments.

For this contract, Eastern Edge has designed a new ROV to both meet and exceed the requirements of the Request for Proposal (RFP) put forth by the Eastman Company. This new ROV is named ROV Calypso (Calypso), is equipped with an all-new electronics enclosure, low latency HD cameras, and more. Calypso has been designed and constructed to complete tasks in dam inspection, waterway preservation, and the safe recovery of historical artifacts and potentially hazardous materials underwater. Calypso's initial budget was set at $5 000 for the 2019 contract to improve capabilities while keeping costs low.

Figure 1: Company Employees, Photo taken at the Marine Institute
(L-R): *David Drover, Keith Sutherland, Victor Linfield, Mark Belbin, Josh Burt, Conquest Eboigbe, Julia Dawe, Charity Talbot, Andrew Troake, Liam Gregory, Stephen Chislett.*
Missing: *Michaela Barnes, Nathan Hollett, Ogheneovo Jatto, Patrick Whelan, Jake Hollett, Keely Lullwitz, Paul Derail, Zack Rooney, Josh Kearney, Nana Abekah, Stephen Snelgrove.*
Photo Credit: Paul Brett

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1.0 Project Management

1.1 Operational Structure

Eastern Edge operates using a horizontal line of communication while maintaining a vertical company structure. This structure enables senior employees to mentor new employees while ensuring effective communication across all departments. To this effect, the company is broken down into four departments: Administrative, Electrical, Mechanical, and Software (Figure 2).

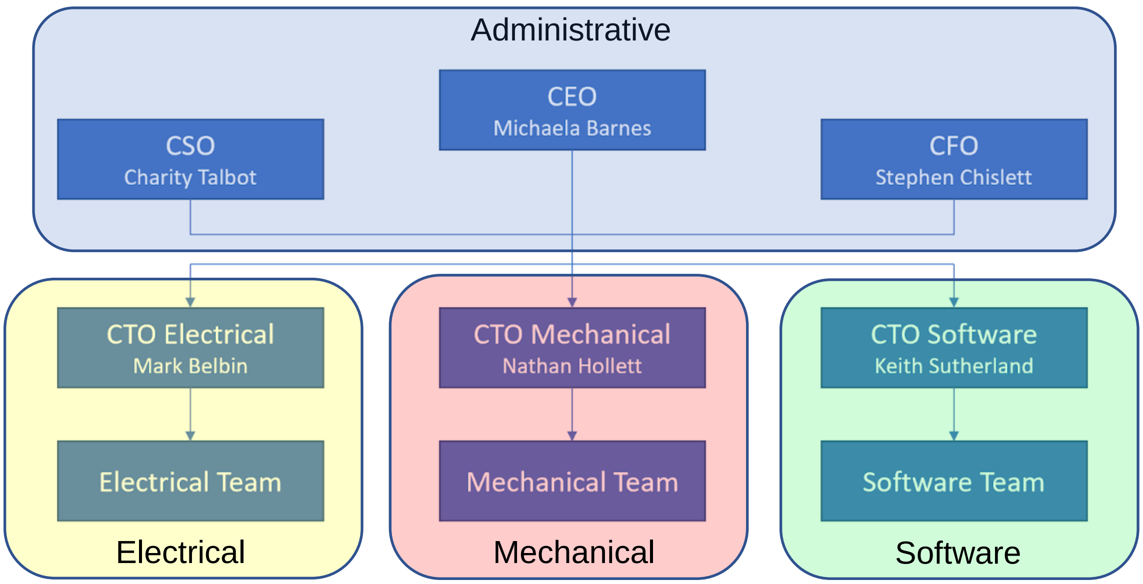


Figure 2: Eastern Edge Robotics Company Organizational Structure

The administrative departments consist of a Chief Executive Officer (CEO), a Chief Financial Officer (CFO), and a Chief Safety Officer (CSO). The role of the CEO is to manage the company and maintain an overarching view of the project and all its components. The CEO assigns roles, consults with department leads and develops and maintains a schedule. The CFO manages the company's finances by tracking all expenditures and earnings, ensuring the project remains within budget. The CSO has the responsibility of maintaining and upholding safety procedures and protocols outlined in Eastern Edge's safety philosophy. All safety documents, including safety passports, Job Safety Analysis (JSAs) and Operational Safety Checklist (OSC) are maintained by the CSO. Each of the technical departments is overseen by a Chief Technical Officer (CTO), creating three positions: Electrical CTO, Mechanical CTO, and Software CTO. Tasks are assigned to department employees through the CTOs to meet company goals. The CTO is responsible for system development within their department and must work with the CEO and CFO to ensure deadlines are met and the budget is adhered to. Employees are assigned to a department based on their discipline of study, skills, and interests. Employees are free to work within multiple departments to expand their skills and increase cooperation between departments.

1.2 Schedule

Eastern Edge began working on a proposal for the 2019 contract in September of 2018. This included developing a schedule in the form of a Gantt Chart (Appendix A). This schedule, created by the CEO in correspondence with the CTOs, indicates the project's milestones. Broken down by department, the chart gives an overview of the project and deadlines between departments. To meet these deadlines, CTOs assigned tasks to their respective departments and were managed and tracked throughout the project.

In September of 2018, the Company held an open house and new employee orientation. This led to an increase in personnel resources and acquiring new talent to the company. Provided no unanticipated interruptions to the progression of standard operations, Eastern Edge predicted completing all aspects of the RFP by May 1st 2019. However, due to unforeseen circumstances, several of the assigned tasks fell behind schedule, which resulted in the revaluation of several tasks and their respective due dates. This pushed the overall timeline back by roughly two weeks. By abiding by a strict and aggressive schedule, Eastern Edge achieved significant milestones throughout the year.

2.0 Design Rationale

For this year's specification presented by the MATE Organization, Eastern Edge made use of a multi-step design process in the development of Calypso. Moving through the steps of brainstorming, initial design, prototyping, design finalization, and completion of final product.

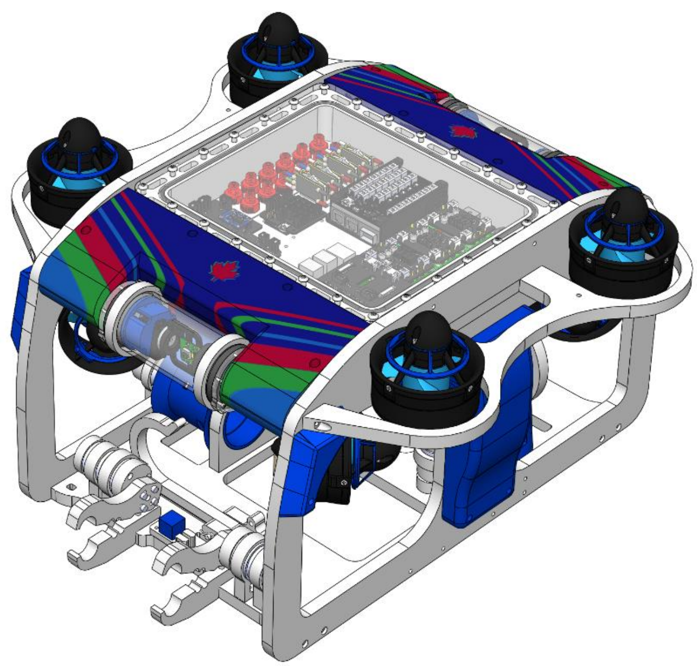


Figure 3: ROV Calypso. Photo Credit: Mark Belbin

Several design requirements were identified throughout the brainstorming and design process of this year's contract. It was decided that the ROV's primary requirement was a clean design that increased the overall power of Calypso in comparison to other market products. This became our design philosophy carried throughout each step of the design process. In tandem, the company also identified the need for a stable vehicle with intuitive controls and ready-to-use payload. Using these philosophies, Eastern Edge presents a simplistic yet powerful design adaptable to the requirements of dam inspection, waterway maintenance, and historical preservation as requested by the Eastman Company. The final design of Calypso, with a weight of 18.5 kg and dimensions of 56 x 55 x 38 cm can be seen above in Figure 3.

2.1 Chassis

Eastern Edge designed the chassis of Calypso to follow a philosophy of simplicity and customizability through a “panel-style” design shown in Figure 4 below. This design supports a wide range of mounting possibilities for tooling, while also providing structural rigidity. This design reduces the number of components, decreasing manufacturing time and allows for more accessible modifications and implementation of new designs. This allowed for an iterative approach during vehicle development, with each vehicle iteration improving upon the last.

Calypso has four major chassis components: two side panels, an electronics enclosure support, and a tooling skid at the base. The electronics enclosure support and tool skid connect the two side panels and hold the chassis together as a unit. Each of these main components has other smaller components attached to them, such as two camera enclosure holders attached to the electronics enclosure support, two vertical thruster guards attached to the side panels, and the various tools that are attached to the tool skid. The aforementioned vertical thruster guards are of particular interest as they serve a dual purpose: both as guards for the thrusters, as well as handles that aid in the transport and deployment of Calypso.

Each component of the chassis is constructed from High Density PolyEthylene (HDPE), a marine grade plastic. This material was chosen for its high strength, similar density to water, and its ease of manufacturing. The density of HDPE is 970 $\frac{kg}{m^3}$ is very close to the 1000 $\frac{kg}{m^3}$ density of freshwater. The similarity in density means that the chassis is slightly buoyant so it does not require extra buoyancy to compensate for the weight of the chassis. Lastly, HDPE is an easy material to work with, as is can be very easily and quickly cut using a Computer Numerical Control (CNC) router. This ease of manufacturing was an asset while constructing the chassis in-house.

The initial prototype was completed and thoroughly tested before designing and prototyping a tooling skid, which is interchangeable. With this modularity, Calypso can be configured for every mission.

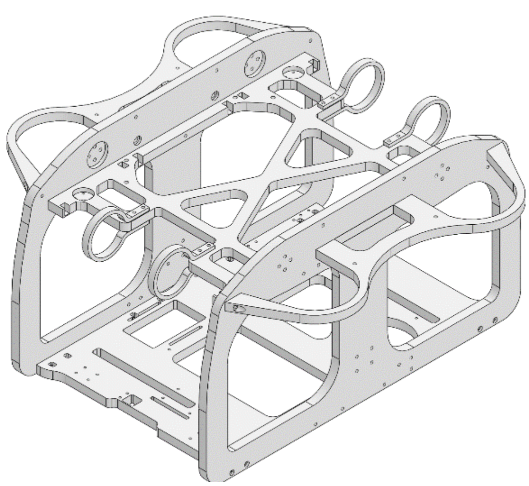


Figure 4: Calypso's Chassis.
Photo Credit: Stephen Snelgrove

2.2 Propulsion, Ballast, and Buoyancy

For optimal maneuverability, Calypso is equipped with eight Blue Robotics T200 thrusters [2]: four lateral and four verticals. The lateral thrusters are arranged on 45-degree angles relative to the edges of the chassis providing three degrees of motion, surge, sway, and yaw. The vertical thrusters are positioned on the top four corners of the port and starboard sides of the frame. This vertical thruster arrangement provides the other three degrees of motion, pitch, roll, and heave. The thruster configuration, shown in Figure 5, depicts the positions of the thrusters relative to Calypso's chassis.

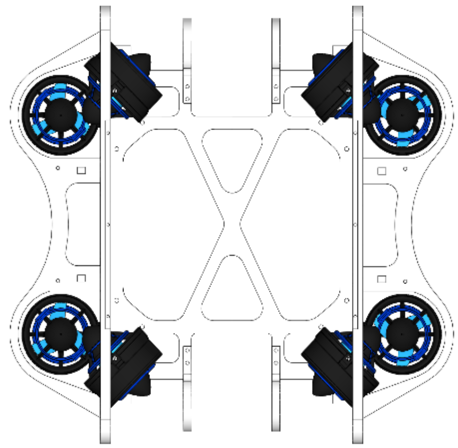


Figure 5: Thruster Configuration. Photo Credit: Mark Belbin

To achieve full piloting and maneuverability potential, Calypso is constructed to be neutrally buoyant. The vehicle employs a static floatation system, constructed from a urethane foam with a material density of 96 $\frac{kg}{m^3}$. Four buoyancy blocks were cut in-house using a CNC router, primed, and painted, then placed on the fore and aft of Calypso's chassis. The buoyancy was designed to be hydrodynamic, cutting through water without excess drag. With this design and Calypso's powerful thrusters, the vehicle can achieve top speeds of up to 1.5 $\frac{m}{s}$.

2.3 Electronics Enclosure

Calypso's electronics enclosure is an all-new design from Eastern Edge. After issues with previous enclosure designs, it was decided that a new electronics enclosure would be necessary for the 2019 contract. This new enclosure features improvements in size, efficiency, troubleshooting ability, and cost.

The company chose to build an electronics enclosure, instead of buy, because commercial off-the-self enclosures restrict the shape of the chassis and placement of tools and thrusters. Designing a custom electronics enclosure meant that the enclosure could be designed to meet the specific needs of the electrical system. The enclosure could be sized to exactly fit the components chosen for the electrical system.

Designed to be the smallest enclosure in the company's history, this design boasts a total volume under 2000 cm^3. This increases the available volume underneath the enclosure, allowing more space for tooling and improving the pilot's sightline through the chassis.

The electronics enclosure utilizes a layered model of three main materials; A bottom plate of aluminum, a body section made of polyoxymethylene (POM) plastic, and a transparent acrylic lid. This layout is shown in Figure 6 to the right. A dual O-ring seal is used to seal all sections, one O-ring between the aluminum and POM and another between the POM and acrylic. Bolts are screwed in from both the top and bottom of the enclosure providing equal sealing pressure on both O-rings. The aluminum bottom plate acts as a heat sink for all electronics, increasing reliability and reducing the chances of overheating. The clear acrylic top allows for full visibility of each component of the enclosure, without having to unseal and open it.

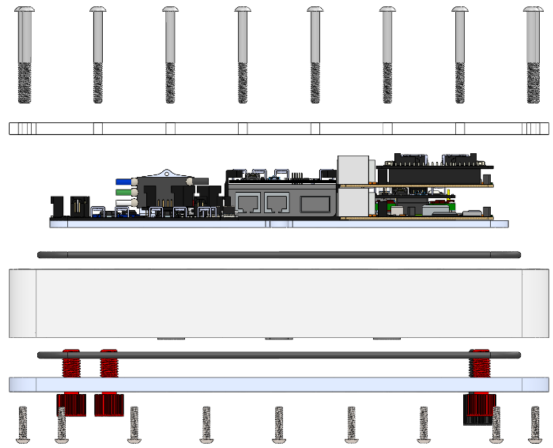


Figure 6: Electronics Enclosure Components. Photo Credit: Mark Belbin

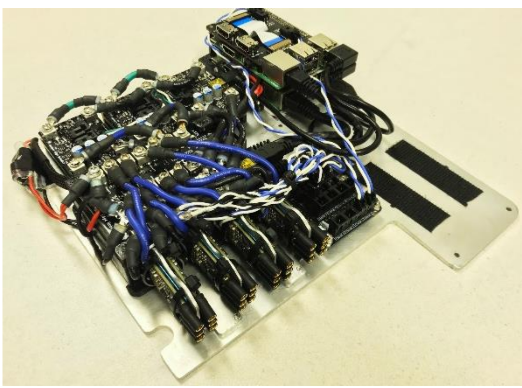


Figure 7: Electronics Enclosure plate. Photo Credit: Mark Belbin

Troubleshooting is an inevitable part of any electronics systems, and the ability to simplify the troubleshooting process was an important design factor for the company. The layout of the electronics, as seen in Figure 7, contains a single layer of electronics mounted on a removable aluminum plate. This way, everything inside the enclosure is visible and easily accessed from all angles. Wires and electrical components do not have to be removed or dismantled during maintenance or troubleshooting. This is a vast improvement from the electronics layout used in Eastern Edge's 2018 and 2017 contract solution, where a double layer enclosure made accessing components difficult.

The three-part enclosure design results in a simple manufacturing process, as all components, can be milled with standard three-axis CNC machines. Although assembled by Eastern Edge. No welds or epoxy joins were necessary, leading to a strong design where the chances of water leakage were minimal. The POM allowed for a less expensive design, as it would have been costly to mill the entire enclosure from a large piece of stock aluminum. The enclosure design, while simple and efficient, required more powerful tools to manufacture than Eastern Edge had access to. Therefore, sections of the enclosure were manufactured by Memorial University's Technical Services and assembled by Eastern Edge.

2.4 Electrical Systems

The electrical system onboard Calypso builds on an architecture that Eastern Edge has used for the last three years. Several refinements and changes were made to improve upon the efficiency of the system. There are 4 major sections of Calypso's onboard electrical system: the power conversion and distribution section, the communications and control section, the thruster drive section, and the peripheral tooling section. Each section is optimized to occupy a low volume while maintaining high performance and functionality; a feat achieved through the use of seven custom PCB designs and optimal off-the-shelf component selection. All PCBs were designed collaboratively using GitHub and the PCB design software, KiCAD. Components were assembled in-house using electronics lab equipment and microscopes. A full System Integration Diagram (SID) of the electrical system is included in Appendix B.

Calypso's power conversion and distribution system are designed to be easily serviced while maximizing available power. The +48VDC at input is converted down to +12VDC using three 95% efficient, 420W, Murata DC-DC converters, for a total power of 1260W. At peak consumption, there is over 100A flowing through Calypso. This power is primarily consumed by Calypso's 8 thrusters through a power distribution PCB, allowing for speed levels higher than those of previous contracts. There are 10 current sensors on the distribution board, enabling current monitoring and control of each thruster for safety purposes. Power telemetry is also monitored through the use of adapter PCBs on each DC-DC converter module. Input voltage is monitored and can be used to reduce system load, avoiding potential brown-out scenarios. An additional circuit was added to these adapter boards to protect the ROV from reverse input voltage polarity, which has been a severe hazard in the past. The circuit was designed and optimized through simulation in LTspice, resulting in a maximum loss of 1.5W between all adapter boards: an efficiency of 99.9% in Calypso's 1260W system.

Calypso's eight thrusters are driven with eight off-the-shelf electronic speed controllers (ESC) from Blue Robotics. Shown in Figure 8, Eastern Edge has created custom aluminum mounts for all eight ESCs, maximizing density, and eliminating disorganized wiring. As well, these aluminum mounts facilitate heat-sinking to the bottom aluminum enclosure plate. ESC's generate a significant amount of heat during operation therefor this design becomes crucial.

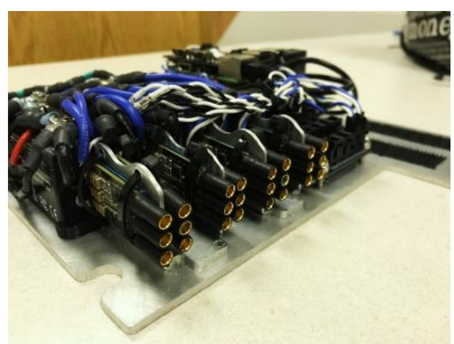


Figure 8: Custom Design of ESC mounts. Photo Credit: Mark Belbin

System control and telemetry are achieved using two Raspberry Pi 3B+, single board computers (SBCs). These SBCs are linked to the topsides control station via a local ethernet network, bridged over Calypso's fiber tether lines through the use of an onboard, multimode fiber-to-ethernet converter. All PCBs are controlled over Universal Serial Bus (USB), utilizing the eight USB ports between both SBCs. The system is designed so that USB components can be added or removed if desired while keeping the core functionalities of the system intact. An example of this is the USB-fiber-converter, which is used for communication to the Micro-ROV. This component was able to fit into the company's system despite being implemented later in Calypso's development. As well, low power PCBs and other devices can be powered over USB cables, eliminating unnecessary wiring.

Tooling requirements were implemented after the RFP was released while initial design and prototyping enabled a head start on the contract. A tooling PCB was designed in-house. It features multiple sensor inputs, DC motor and LED drivers and an Inertial Measurement Unit module for software-assisted piloting and autonomous missions. Sensor data is collected, and the actuators are driven through USB communication facilitated by an onboard SAMD21 microcontroller. The use of a custom PCB decreased required enclosure volume substantially compared to using separate commercial components. As well, the company was able to design circuits to meet the specifications of the RFP, which was a determining factor to build/design rather than buy. Three of the seven custom PCB's designed can be seen below in Figure 9.

Figure 9: Custom designed Power Distribution, DC-DC and Tooling Printed Circuit Boards. Photo Credit: Mark Belbin

Calypso's redesigned camera system for 2019 incorporates all-new Internet Protocol cameras. Two of these cameras stream 720p HD, and 60 FPS video to the company's topsides control system, with a latency of only 80 ms, an improvement from previous designs, avoiding control issues previously encountered. Both are standard Raspberry Pi V2 cameras, but the critical advantage is how they are deployed. Each camera is connected to one of two onboard Raspberry Pi 3B+ SBCs. Utilizing the best encoding capabilities for camera streaming, reducing latency, and increasing video quality. To send the video to the topsides, the company uses an open-source library using UDP pipelines. Calypso's cameras enclosure can be seen to the right in Figure 10.

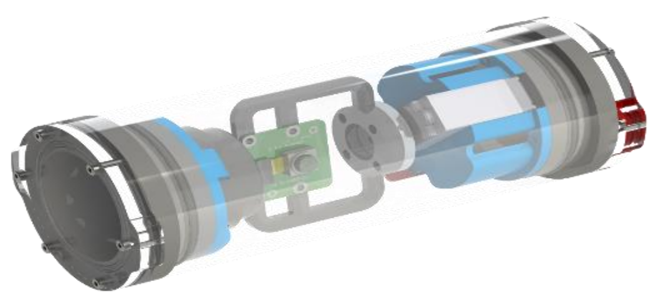


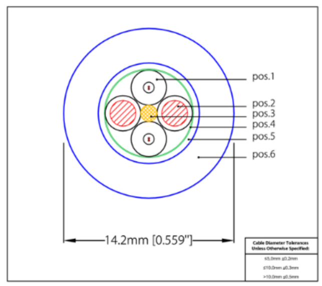
Figure 10: Calypso's Cameras. Photo Credit: Mark Belbin

Eastern Edge has developed an all-new solution to enable the remote placement of camera modules; sending camera signals over a standard HDMI cable. This is accomplished with a custom-designed adapter PCB, and careful cable termination using a microscope. Low cost and readily available HDMI cable can easily be waterproofed through a cable penetrator, unlike a standard ribbon cable. A smaller PCB was used to convert the individual HDMI conductors back into a ribbon cable format that can be plugged into the camera module. As well, servo power and signal lines are fed through the HDMI cable, reducing the number of cables entering each camera tube module to just one, allowing for clean cable management.

2.5 Tether

Calypso's tether was designed by Eastern Edge during a previous contract, and was fabricated and donated by Leoni Elocab. This tether meets all of Calypso's capability requirements and re-using this component results in lower the cost of the 2019 ROV.

This tether contains two multimode fiber sets for communication and two 14 American Wire Gauge (AWG) conductors for power. The buoyant outer jacket makes the tether neutrally buoyant, aiding in tether management. These components are shown to the right in Figure 11. Eastern Edge uses multimode optical fibers for their high bandwidth, reliability, electrical noise immunity, and lower mass when compared with copper alternatives.



Pos. 1	Fiber Optic component(s)
Pos. 2	Insulated wires, 14 AWG
Pos. 3	Filler
Pos. 4	Binder
Pos. 5	Polyurethane - Jacket
Pos. 6	Polyurethane Foam - Jacket

Figure 11: Tether Cross Section. Photo Credit: Charity Talbot

2.6 Software

This year, the software for Calypso was redesigned in Python and was inspired from previous years while improving key weaknesses. Eastern Edge took a general approach to the overall software architecture with modularity as a key focus. With this approach, the software contains code for specific missions while having the capabilities for easy expansion in the future.

Eastern Edge utilizes a Python micro-framework called Flask. Flask is a web service framework that handles the Hypertext Transfer Protocol (HTTP) communication. A Flask web server is hosted on the topsides computer which clients can connect to. The server can handle multiple clients asynchronously. Static Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), and JavaScript files are sent to the clients when connected to act as the user interface. Clients can send HTTP GET and POST commands to the web server, which will run Python snippets that interact with Calypso's communication software.

By using HTML, CSS, and JavaScript for the user interface, it is easy to alter and expand on the platform. The only requirement to view the user interface is a web browser. This allows for the software to be used on almost any device which includes: computers, cell phones, and tablets.

Networking communications is achieved using Python to enable communications between the computer hosting the Flask server and the Raspberry Pi SBCs that are on the ROV. The Python socket library is used as it provides quick and extensible communications in various forms, with the form being User Datagram Protocol (UDP). This was chosen over Transmission Control Protocol (TCP) as UDP is faster and a loss-tolerant protocol. However, with the amount of data being sent, losing a few packets will not affect ROV performance.

Once data packets arrive at the ROV, they are each executed in separate threads which has the ability to send information back to the topside's server. If data packets are no longer sent to the ROV, it will be registered as a loss of communication and automatically power down all moving systems as a safety protocol. An overview of software communication can be shown in Figure 12.

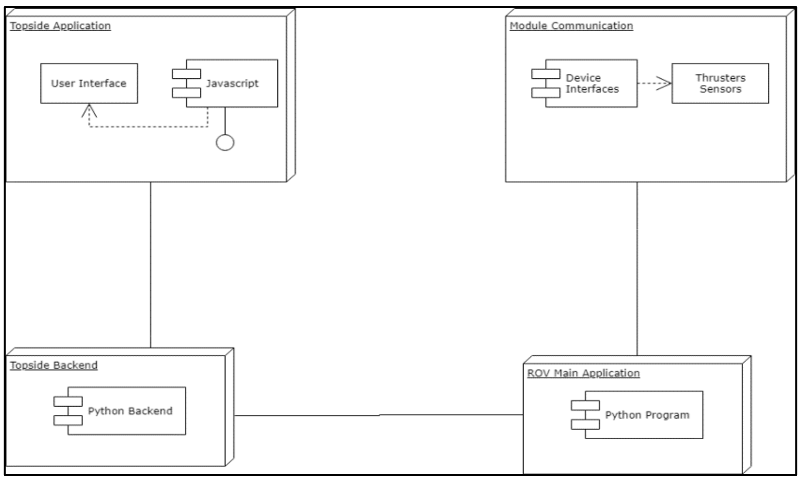


Figure 12: Software Communication Overview.
Photo Credit: Keith Sutherland

Based on the RFP, computer vision was needed to complete tasks. This includes autonomously inspecting the dam, measuring and mapping a crack in the dam, and examining benthic species. The company used the image processing library OpenCV to accomplish this.

The line following algorithm minimizes computing power by creating five small areas for image processing. These areas are used to detect the directions that the line is going relative to the center of the camera feed, and centering the ROV on the line. Given a known previous direction, it can use these areas of interest to determine the next direction to take. It also can use the width of the line to determine distance from the dam and can detect black transecting lines to determine the location in the grid. While running this algorithm, it also runs an algorithm to mask any blue shapes to find the crack location.

To determine the length of the crack, the program first places a Gaussian blur on the image for better edge and corner detection. It then converts the image from a RGB (red, green, blue) to a HSV (hue, saturation, value) format. The program then isolates the blue in the image received from the ROV so the corners of the blue crack can be detected.

The coordinates of each corner are used to calculate the average length of the line in pixels, which is then translated to cm by using the known width of the crack (~1.8 cm). This result is then displayed on the screen to the closest 0.1 cm.

The initial process for the benthic species detection and counting program is similar to the blue crack detection. It smooths the image to reduce the amount of noise and creates a binary mask to resolve the image to a set of sharp black and white shapes. The algorithm then detects the contours of each shape to determine which shape it is by using the possible number of sides. In order to be considered, each shape must be of a minimum size. For example, if the number of sides is three, then the shape is counted as species A. Since species B and C both have four sides, they are differentiated between each other based on the ratio of their width and height. Once all the species are detected and counted, all four species are drawn in red in the lower left corner of the screen with the respective number of species next to them.

The current control system includes auto stabilization and depth control algorithms. These control algorithms are built on a Proportional Integral Derivative (PID) methodology. PID is a control loop feedback algorithm used in industrial control systems to regulate temperature, current flow, speed, and other variables. The depth control algorithm uses a pressure sensor on the ROV to track its depth and allows the pilot to lock the ROV at any given depth. This algorithm calculates the power needed to reduce the difference between the ROV's position and its target position. The auto stabilization algorithm prevents the ROV from rolling and pitching when it is not commanded to do so by the pilot. This allows the pilot to fly around smoothly without having to make adjustments to keep the ROV stable. This algorithm uses a gyroscope to track the yaw, pitch, and roll positions of the ROV which are fed to the algorithm for computing the true power needed to keep the ROV stable.

2.7 Payload and Tooling

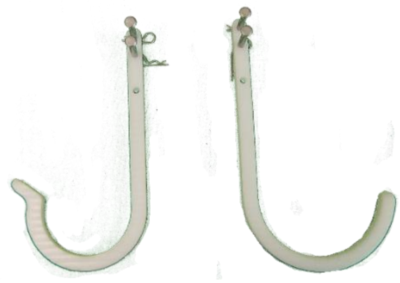
Fish Bowl

The Fish Bowl is a dual-purpose containment and delivery device for both the trout fry and the grout. It is comprised of a caged enclosure on the interior of the ROV with a motor operated rotating floor on the bottom of the cage which acts as the access and deployment point.

Rock Lobster

Eastern Edge designed and manufactured two moving claws mounted to the fore of Calypso to aid in the completion of several missions. The Rock Lobster is constructed from HDPE mounted to two DC motors. Each claw has a fixed lower jaw horizontally attached to the ROV frame and a motorized upper jaw that allows for the claw to be opened and closed as needed. The claws are shaped to optimize the placement, movement, and retrieval of various objects underwater.

Captain Hooks



The Captain Hooks consist of two HDPE machined claws attached to the bottom of the ROV. Each claw is attached to the ROV using two clevis pins. These pins can be moved between two positions around a central pivot point to deploy or retract the claws as they are needed. The two claws face opposite directions and are different sizes made to fit both the larger and smaller diameter sections to successfully lift the cannon.

Sensors

The ROV has a potted waterproof pH sensor located on the fore of the ROV. It is secured to the tooling skid of the ROV using two pieces of HDPE and has 3D printed teeth to pierce the seal on the situ water sample. The sensor sends back a signal of the detected pH of the water through the customized tooling board. Calypso also has a waterproof temperature sensor attached to its side. This sensor sends ambient water temperature data to the tooling board which are forwarded to the topsides control module.

Light Brites

Calypso has two LED lights mounted to the fore of the chassis. These lights are made from repurposed cabinet light strips potted to be waterproof. They are dimmable using the tooling board and are used to illuminate areas of interest for image recognition, such as the benthic species and dam inspection.

Metal Detector

Calypso has a potted, waterproof metal detector located on the front of the ROV. It is secured to the tooling skid of the ROV using a piece of HDPE. When the sensor is used to detect the metal cannon shells, a red light will turn on which can be seen through the cameras. The sensor will also send a signal through the tooling board indicating that it has detected metal.

2.8 Micro-ROV

Eastern Edge determined that a design similar to a Blue Robotics Autonomous Underwater Vehicle (AUV) was better than the alternative designs proposed. As the micro-ROV must traverse into the pipeline at a 90-degree angle over 2.4 ft, other preliminary designs were determined too bulky and less cost-efficient. Upon investigating the operating conditions, an AUV design was created using a single OpenROV thruster. This was chosen as it was on-site and provides the sufficient thrust to propel the micro-ROV. In addition, the small form factor allowed for narrow design compared to other solutions. The choice to use fiber optics to transfer data was made as components were readily available. The final design of Odysseus can be seen below in Figure 13.

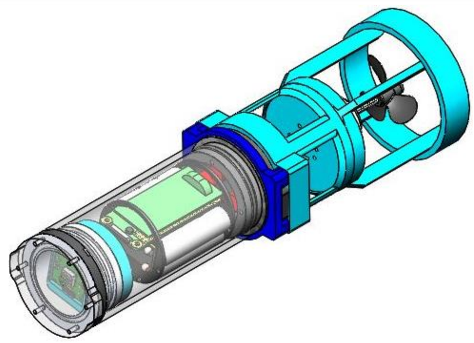


Figure 13: Micro-ROV Odysseus. Photo Credit: Josh Burt

Odysseus runs on six AA Duracell Quantum batteries in a 6s1p configuration, giving a max operating voltage of 10 volts and a capacity of 2500 mAh. The batteries are housed in a custom holder which is a 3D printed part fitted between two custom PCBs. With the battery holder, maximum energy density is achieved, and batteries can easily be replaced in the field. One side of the battery holder has a six-amp fuse and a latching button to reduce the number of wires. The SID for Odysseus is shown below in Figure 14.

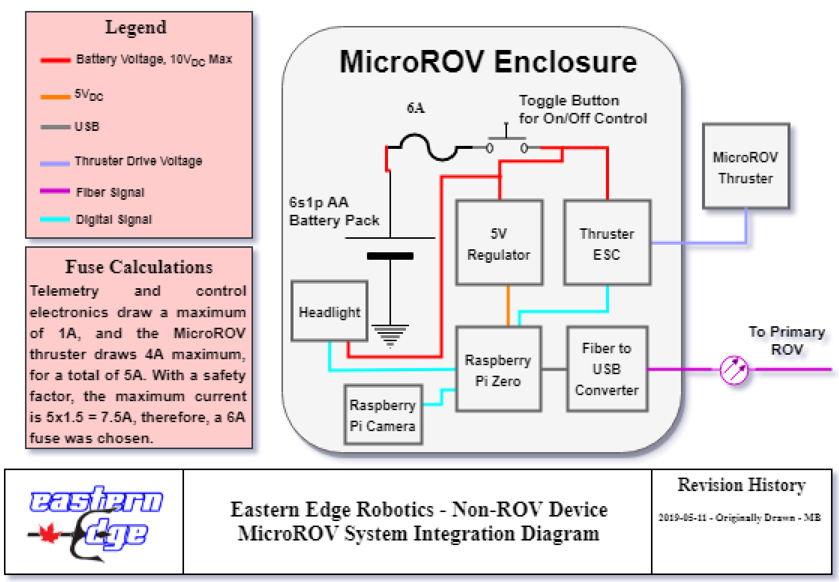


Figure 14: Micro-ROV SID. Photo Credit: Victor Linfield

Odysseus is equipped with one OpenROV kit thruster that has been waterproofed by removing the stator and covering any wire with a layer of marine grade epoxy. A Megaohm test was performed to ensure adequate insulation from the water. To power the OpenROV thruster, the same ESC model as Calypso was used due to its small form factor. A Raspberry Pi Zero controls the ESC and transmits the feed from a camera mounted at the front of the micro-ROV. A small DC-DC converter powers the Raspberry Pi. For communication to the micro-ROV a USB-to-fiber optic converter is used to create a USB Ethernet connection with a Raspberry Pi 3B+ onboard Calypso.

3.0 Safety

3.1 Safety Philosophy and Protocols

At Eastern Edge, the safety of the company employees, the environment, and the public are the primary concerns. The Company has put in place numerous safety protocols to achieve an open safety culture. Employees are ensured to a safe working environment and are encouraged to speak about any concerns. This enforces the safety philosophy: nobody gets hurt.

The company utilizes toolbox talks which includes the use of a JSA and has implemented an operational procedure/checklist which is used while operating the ROV. Toolbox talks are performed at the beginning of each work day, which entails the technical leads presenting daily tasks and filling respective JSA's. This fosters a safety conscious work environment, reducing the likelihood of injury and increasing efficiency and effective work practices. JSA's encourage personnel to follow safe working procedures and reminds employees the importance of using Personal Protective Equipment (PPE).

Safety Passports, which were introduced to the company in 2017, are still being used as a method of recording employee health and safety training. An employee must have the required safety training before receiving permission to use tools. For each tool, a mentor must conduct training – which includes being shown the proper PPE, a verbal explanation of proper operating procedures, and is then monitored using the equipment. After such, the CSO will sign off on the specified training. The use of safety passports is not only a record of training, but also ensures that employees have been properly trained and eliminates the possibilities for injuries.

3.2 Safety Features

Calypso exceeds all safety requirements outlined in the 2019 contract. Calypso's safety features include, but are not limited to: a 30 Amp fuse within 30 cm of the ROV power supply; thruster guards rated to IP20 standards; smooth and rounded edges on the vehicle and all auxiliary components; warning labels on moving components and power connections; and strain relief on the vehicle's tether located on both ends. The ROV also has integrated software kill switches, which includes a safe mode for potential emergencies. Eastern Edge continues to use threaded inserts to replace nuts – which in turn reduced the number of protruding metal components on the chassis and the potential for hazards.

4.0 Critical Analysis

4.1 Testing and Troubleshooting

Eastern Edge recognizes that a testing and troubleshooting procedure must be implemented and is key to creating a reliable product. For this reason, the company's protocol is to test and troubleshoot components and proposed systems before complete integration. By testing components and systems independently, any problems that arise can be isolated and resolved quickly and efficiently without damaging the entire project. The camera system was extensively tested for latency and functionality using a prototype camera test-bed, shown in Figure 15. Simultaneously, the mechanical department tested the electronics enclosure and penetrators throughout the design and prototyping phases to locate and eliminate potential leaks. As well, the Chassis was modeled in Solidworks before construction, and a Finite Element Analysis (FEA) was performed to locate any weaknesses in the structure. These tests could identify any flaws with the design of components before final implementation. Since Eastern Edge decided to custom design and built the electronics enclosure for Calypso, the enclosure had to be tested multiple times, ensuring that it could withstand the pressure at a depth of five meters as per safety specifications. This resulted in an FEA test, shown in Figure 16, determining the design had the capacity. Once prototyped, the enclosure was tested to ensure that the design specifications were met.

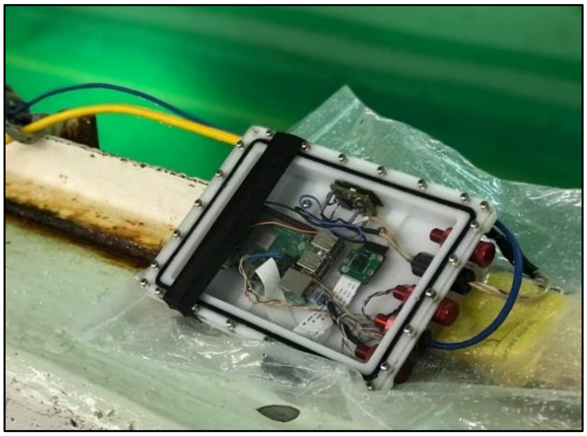


Figure 15: Camera test-bed.
Photo Credit: Mark Belbin

Calypso was tested in the tank facilities at the Marine Institute. This is where the company's pilot spent many hours practicing mission tasks and noting ways to improve different control systems or tools. Extensive testing was performed on all systems as improving the performance and experience of the ROV for the client is the company's goal.

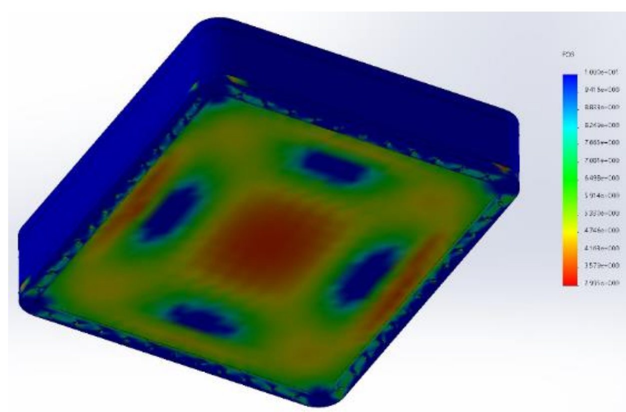


Figure 16: Stress FEA results on electronics enclosure.
Photo Credit: Nathan Hollett

4.2 Challenges

Technical Challenges

A major technical challenge occurred to the company the night before filming the required demonstration video for the MATE contract. Due to poor communication with company employees, a valve used to test the pressure seal of the primary enclosure was not closed after an in-air pressure test. Calypso was placed in the water for buoyancy testing with the valve left open. Once a company employee noticed the water filling the ROV, the enclosure was approximately three-quarters full. Fortunately, the power supply for the ROV was not connected as the company employees were performing just a buoyancy test. However, even with no power, water can damage many of the custom PCBs and other components such as the fiber switch inside the primary enclosure.

The employees were able to take Calypso from the water and quickly remove the top cover of the enclosure. Many of the electronics close to the top of the enclosure were untouched by the water. Therefore, the water had to be safety and carefully removed to ensure that more electronics were not possibly affected by it. Due to the design of the enclosure, the plate holding the electronics was easily removed less than five minutes after the water was noticed by the employees.

The company was able to remove all electronic components from the electronics plate. All custom PCBs and other components were cleaned using the company's flood cleaning procedure. This included all components receiving an isopropyl alcohol bath and being placed in a dehydrator. After 24 hours, each electronic component was tested individually. After each component passed the respected test, the electronics were reassembled in the enclosure, and a full system test was performed with positive results. The company was able to film the demonstration video the following day, resulting in only a one-day delay for the project.

Interpersonal Challenges

During the 2019 contract year, the company started accumulating multiple safety incidents in a short period. This was due to a lack of communication and respect for rules when it came to talking about safety and providing a safe working environment. Following a Loss Time Incident (LTI), the CEO and CSO began evaluating and enhancing the procedures and policies regarding safety. This also involved meeting with the facility heads to determine the best route to follow for the company. Throughout this process, Eastern Edge temporarily lost access to the facilities, and this caused tension and a delay of work throughout the company.

New safety procedures were implemented throughout the company involving identifying and talking about safety hazards. Thus, creating an open safety culture and drastically decreasing the frequency of incidents. As a direct result, communication throughout the company increased, increasing productivity. Eastern Edge prioritizes safety before all else, and it is important that safety is abided by at all times as consequences may occur.

4.3 Lessons Learned

Nana Abekah, New Junior Employee, Software Team

I joined the company in September 2018 with the assumption that there would not be many technical software challenges to work on. It was my first experience with underwater ROVs. This assumption, however, was proven to be very wrong. Before joining this company, I had little to no experience with embedded systems, Linux OS, Raspberry Pi, and feedback control algorithms. With the help of great mentors and employees, I have gained advanced knowledge in these fields allowing me to build my own robotic systems. I was assigned to work on Pilot-Assisted-Controls. My task was to include autonomous systems such as momentum compensation, depth, and angular control. I had not worked on any of these autonomous features before joining the company. Through this project, I learned how to effectively communicate my ideas with the CTO, the software department, and, the electrical department. I learned to troubleshoot effectively, communicate my results, and ask for help when needed. My presentation skills have improved, as well. The company organizes a meeting at least once a week, where employees get the opportunity to improve our presentation and communication abilities. In nine months, I have become a better robotics engineer, and presenter, because of this excellent company that I decided to join.

Michaela Barnes, Departing Senior Employee, CEO

This is my fourth and final year as an employee of Eastern Edge, and my ninth year competing in a MATE ROV Competition. The skills I have gained and the lessons I've learned through this experience have propelled me through my studies and now into my future career. Through Eastern Edge, I gained a fundamental understanding of electronics, mechanical structures, and ROV systems through the design of new products. I gained practical shop skills using power tools and machinery – such as the CNC router, the 3D printer, and various hand tools – throughout the manufacturing phases. I have also gained basic critical thinking and troubleshooting skills that have changed the way I think and approach problems in all aspects of my work and life. As CEO of the company I have gained immeasurably valuable leadership and organizational skills that have gotten me a number of internships and jobs in the ocean industry. I have also gained communication skills through inter-departmental work and the number of presentations and reports completed through the company. The most important thing I've gained over the last nine years is confidence in myself, my technical abilities, and my abilities as a leader. I am grateful to Eastern Edge Robotics and the MATE Organization for many years of stress, fond memories, and lessons learned.

4.4 Future Improvements

Reflecting on the year, Eastern Edge has room to improve upon company communication and delegation of tasks. A major problem that was faced this year was that many company employees were relocated outside of Newfoundland and Labrador due to educational program requirements. This included the majority of the mechanical team. Having employees located in various locations requires communication to be consistently upheld, and the company struggled with this throughout the year. This resulted in poor delegation of tasks between the various employees. Many employees were left uninformed about the status of the ROV and had issues completing design work remotely. An unmanageable amount of work was left for the number of employees remaining in Newfoundland and Labrador. To improve upon these problems, Eastern Edge will implement a preliminary task allocation system for the beginning of the next year's contract. This will allow employees to decide a focus for their contributions to the ROV.

In addition, Eastern Edge experienced issues with the hydrodynamics of the ROV. The ROV was designed to be the most powerful model to date. This power came at the price of dynamic stability of the ROV. In the future, Eastern Edge will strive to develop a layout optimal for the most efficient movement through the water. By consulting with industry professionals in the area of hydrodynamics, the company will gain new insight into this design challenge.

5.0 Accounting

5.1 Budget

At the beginning of the year, each of the departmental CTOs were asked to create a preliminary cost estimate. This included all items anticipated to be required for the completion of the upcoming contract. The preliminary cost estimate for the fabrication of the ROV was estimated to be $4 892.74 (Appendix C). The budget for the 2019 contract (Table 1), shows the income and the expenses of the company.

Budget				
School: Memorial University of Newfoundland and Labrador			Reporting Period	
Company: Eastern Edge Robotics			From:	2018-09-30
			To:	2019-05-15
Income (at start of the project)				
Source				**Amount**
Fisheries and Marine Institute				$10,000
Memorial University				$10,000
MATE ROV NL Regional Sponsors				$20,000
			Total:	$40,000
Expenses				
Category	**Descriptions/Examples**	**Type**	**Projected Cost**	**Budgeted Value**
Electrical	Custom PCBs, wire, boards	Purchased	$2,360.92	$2,500.00
	Thrusters (4)	Re-used	$887.88	-
	Thrusters (4)	Purchased	$887.88	$887.88
	Cameras	Purchased	$174.05	$200.00
	Sensors	Purchased	$115.84	$130.00
	Tether	Re-used	$581.40	-
Mechanical	Chassis	Re-used	$210.30	-
	Electronics enclosure materials	Purchased	$924.66	$950.00
	Tooling motors	Purchased		
	Buoyancy material	Purchased		
Shop Materials	Camera tubes and enclosure	Purchased	$292.47	$300.00
	Epoxy, safety equipment, paint	Purchased	$200.00	$200.00
	PVC, PVC fittings	Re-used	$350.00	-
Travel	Flights and hotels for 22 people	Purchased	$35,000.00	$35,000.00
	Rental vehicles and miscellaneous	Purchased	$3,000.00	$3,000.00
				$43,167.88

Table 1: Eastern Edge's Budget

Additionally, the costs for travel to and from Kingsport were estimated early in the year, so that a budget could be set. Initially, the cost of travel and accommodations was estimated at $38 000 (Table 1). Provided this estimate, the travel budget was set at $39 000 to account for miscellaneous costs.

5.2 Project Costing

After the development of the ROV budget as well as the travel budget for the year, Eastern Edge began purchasing components for fabrication of the chosen vehicle design. While several of the components used in this year's contract were purchased new, several components were already on hand and were reused for this contract. This ability to reuse components allowed Eastern Edge to save money on the fabrication of Calypso. By following the budget created early in the year, Eastern Edge was able to remain within the set budget during the fabrication of Calypso. The cost breakdown in Appendix C shows the cost of Calypso's components that were purchased for this year's contract totaling to $4 892.74; with all of the used components amassing a fair market value of $5 294.87.

6.0 Acknowledgments

Eastern Edge would like to thank the following organizations for their monetary support in the development of Calypso, company travel to Tennessee, and of the MATE ROV Competition both regionally in Newfoundland & Labrador and internationally: Eastman Foundation; Atlantic Canada Opportunities Agency; Crosbie Group Limited; Department of Tourism, Culture, Industry and Innovation; Fugro GeoSurveys Inc; Hibernia Company Ltd; Husky Energy; Kraken Robotics; Marine Institute of Memorial University; Memorial University Faculties of Engineering and Science; Memorial University Technical Services; Statoil Canada Ltd; SubC Imaging; Subsea 7; ExxonMobil; RobotShop; Colab Software; Raspbian and Women in Science and Engineering Newfoundland. Eastern Edge would also like to thank the following organizations for donating software or material resources: GitHub; Leoni-Elocab; and Solidworks.

Finally, the Company extends a heartfelt thank you to the mentors Paul Brett, Joe Singleton, Anthony Randell, Shawn Pendergast, Chris Batten, and Jennifer Howell for their time, administrative support, and unwavering encouragement, as well as to the MATE Center for making this all possible.

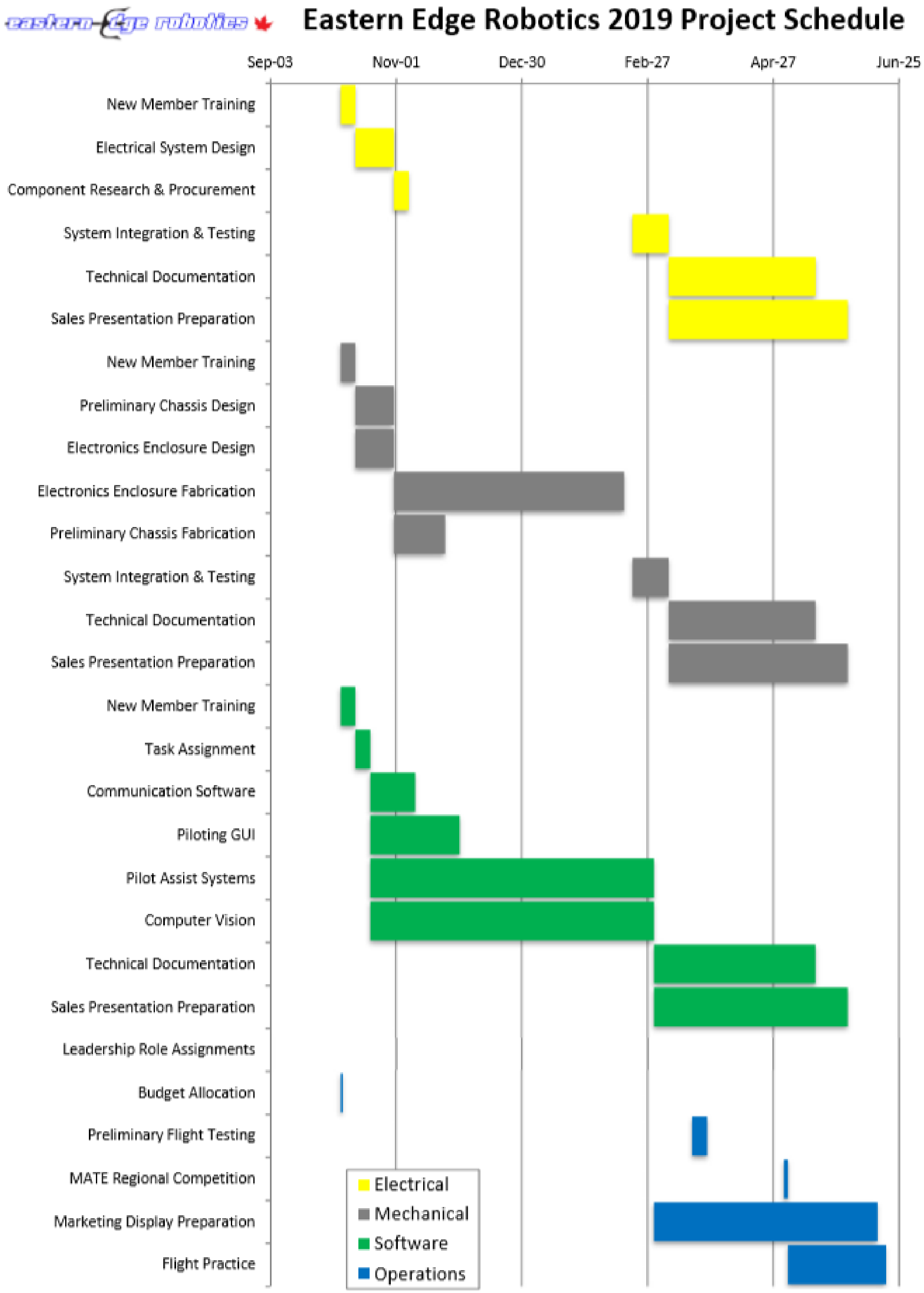
7.0 References

[1] Murata Power Solutions, *DBQ/DVQ Series*. 2019, p. Murata.

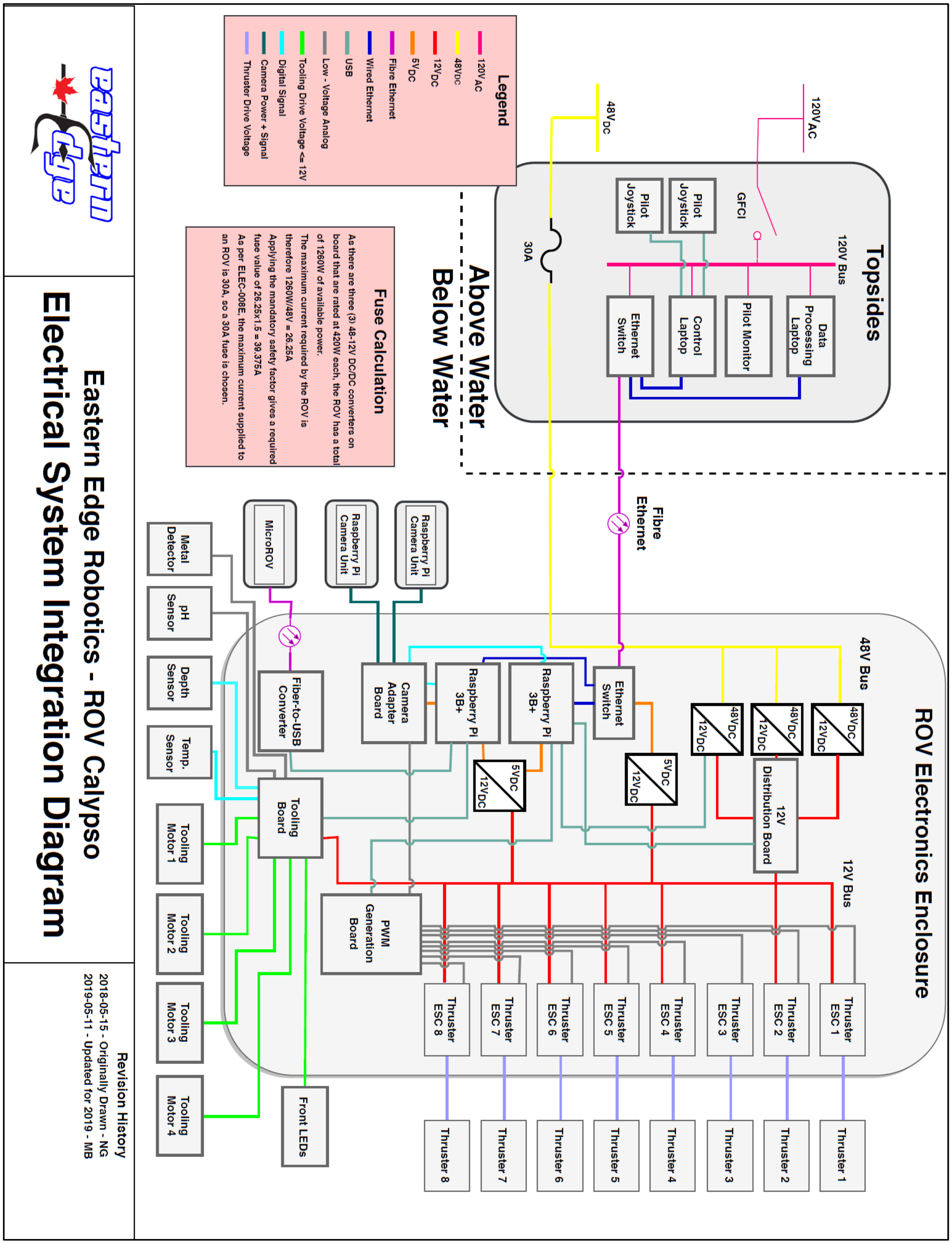
[2] Blue Robotics, "T200 Thruster Documentation", *Blue Robotics*, 2015.

[3] MATE, "MATE ROV Competition Manual Explorer," *MATE*, 2019.

Appendix A – Preliminary Project Schedule



Appendix B – Calypso System Integration Diagram (SID)



Appendix C – ROV 'Calypso' Project Costing

School: Memorial University of Newfoundland and Labrador			Company: Eastern Edge Robotics	Reporting Period: 2018-2019	
Date	**Category**	**Expense**	**Description**	**Type**	**Amount**
2018-11-07	Electrical	Electrical Hardware	Bullet connectors, resistors, and capacitors	Purchased	$ 157.20
2018-11-07	Electrical	Custom PCBs	Power distribution, DC/DC, camera, & tooling boards	Purchased	$ 164.17
2018-11-07	Electrical	Cables	USB, HDMI, Ethernet, and Ribbon Cables	Purchased	$ 204.53
2018-11-07	Electrical	Wiring	12, 14, 16AWG copper wire, heat shrink	Purchased	
	Electrical	Switch	0.05A 32V Fibre - Ethernet Switch	Purchased	$ 87.14
	Electrical	Sensors	Blue Robotics Pressure Sensor and board	Purchased	$ 107.71
	Electrical	Sensors	Current Sensor and board	Purchased	$ 77.44
	Electrical	Computer Board	Raspberry Pi 3 B+	Purchased	$ 103.98
	Electrical	Cameras	2 Raspberry Pi Cam Modules Wide Angle	Purchased	$ 37.98
	Mechanical	Camera Motors	Hitec Mini Servo	Purchased	$ 61.73
	Mechanical	Camera Enclosure	Blue Robotics Acrylic 2" Tube	Purchased	$ 41.37
	Mechanical	Camera Enclosure	Blue Robotics Acrylic 2" O-Ring Flange	Purchased	$ 46.51
	Mechanical	Electronics Enclosure	O-rings	Purchased	$ 51.55
	Mechanical	Penetrators	Blue Robotics M10 Cable Penetrators	Purchased	$ 166.46
	Mechanical	Electronics Enclosure	Acrylic lid, plastic stock, and aluminum plate	Purchased	$ 345.00
	Mechanical	Electronics Enclosure	MUN Tech Services Labour	Donated	$ 150.00
2016-2017	Mechanical	Thrusters	Blue Robotics T200 Thrusters (4)	Re-used	$ 853.13
	Mechanical	Thrusters	Blue Robotics T200 Thrusters (4)	Purchased	$ 853.13
	Mechanical	Hardware	Screws, Locknut, Inserts, Countersink	Purchased	$ 265.31
	Mechanical	Buoyancy Block	Urethane Foam Sheet	Purchased	$ 141.16
	Mechanical	Buoyancy Block	Primer and Paint	Purchased	$ 63.80
	Shop Supplies	PPE	Painters Ventalation Mask	Purchased	$ 68.59
	Shop Supplies	Tools	Blue Robotics Penetrator Wrench, Potting kit, Vacuum Pump	Purchased	$ 54.90
	Shop Supplies	Materials	Epoxy, endmills, 3D printer filament	Purchased	$ 423.88
	Administrative	Shipping/Customs	Various shipping and customs not included in individual purchases	Purchased	$ 569.80
	Electrical	Speed Controllers	Blue Robotics Basic ESCs	Purchased	$ 299.25
	Electrical	Tether	Leoni Elocab Fibre / Copper wire tether	Donated	$ 581.40
	Electrical	Tooling Motors	Gearmotor 12V Motors (6RPM, 10RPM, &225RPM)	Purchased	$ 104.64
	Mechanical	Chassis	1" White HDPE	Re-used	$ 222.57
2017-2018	Software	Laptop	Dell Laptop	Re-used	$ 974.99
2016-2017	Electrical	Switch	5 Port Switch with PoE + Fibre SFP	Re-used	$ 66.50
	Mechanical	Micro-ROV	2" BR Acrylic Tube, endcap, o-ring	Purchased	$ 195.00
2019-01-12	Administrative	Photo Editing Software	Adobe Photoshop 2016 License	Purchased	$ 137.86
2019-04-21	Electrical	Sensors	Gravity Analog pH Meter	Purchased	$ 39.33
2019-04-21	Electrical	Sensors	Afinibot PL-08N A3S (Metal) Proximity Sensor	Purchased	$ 23.32
				Total Cost:	**$ 4,892.74**