Company Employees

Name	Role/Discipline
Anthony Randell	Chief Executive Officer
Adam Pelley	Chief Financial Officer
Calvin Gregory	Chief Operating Officer
Racheal Seymour	Chief Safety Officer
Nick Graham	Chief Technical Officer - Electrical
Nathan Ash	Chief Technical Officer - Mechanical
Nick Martin	Chief Technical Officer - Payload
Whymarrh Whitby	Chief Technical Officer - Software
Keely Lullwitz	Pilot
Christian Samson	Electrical
Zachary Brown	Mechanical
Will Glatt	Mechanical
Evgueni Sapojnikov	Mechanical
Adam Tremblett	Mechanical
Sarah White	Mechanical
Michaela Barnes	Payload
Tybalt Lea	Payload
Halie Murrin	Software
Cal Pratt	Software
Keith Sutherland	Software
Connor Whalen	Software

Company Mentors

Paul Brett, B.Sc (Hons), B.Ed Post Secondary, M.Sc

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

Jai Ragunathan, B.Eng., B.Ed Post Secondary, M.Eng

Joe Singleton, P.Eng

Craig Bulger, B.Sc (Hons)

Memorial University, St. John's, Newfoundland and Labrador, Canada
MATE International ROV Competition 2016, Explorer Class

1.0 Abstract

This technical document presents Blue Puttee, an Explorer class Remotely Operated Vehicle constructed as a deliverable for the 2016 Marine Advanced Technology Education Center's international Remotely Operated Vehicle competition. This vehicle was designed and manufactured by Eastern Edge Robotics, a company dedicated to developing robust solutions to perform work in harsh subsea and extraterrestrial environments. Blue Puttee was developed to address the specific needs outlined by potential clients in the planetary science, aerospace, and offshore oil and gas industries.

Blue Puttee is composed of a high-density polyethylene structure supporting an aluminum electronics enclosure and six brushless thrusters. It uses two rotating, high-definition cameras and a primarily passive custom payload system. Blue Puttee has been designed to meet the strict size and weight limitations associated with space travel. The resulting vehicle is simple, robust, and effective. Blue Puttee's control system is implemented in the Java programming language and utilizes a distributed network of computers. A custom-designed tether connects the onboard electronics to the Topside Control Module: an integrated unit containing all the necessary equipment required to operate the vehicle.

Throughout the development process Company employees have learned essential technical skills and worked diligently to deliver a quality end product, dedicating over 9500 hours to the development and manufacture of the vehicle and over 250 hours to operations. The fair market materials value of Blue Puttee is $6,543.86 USD.

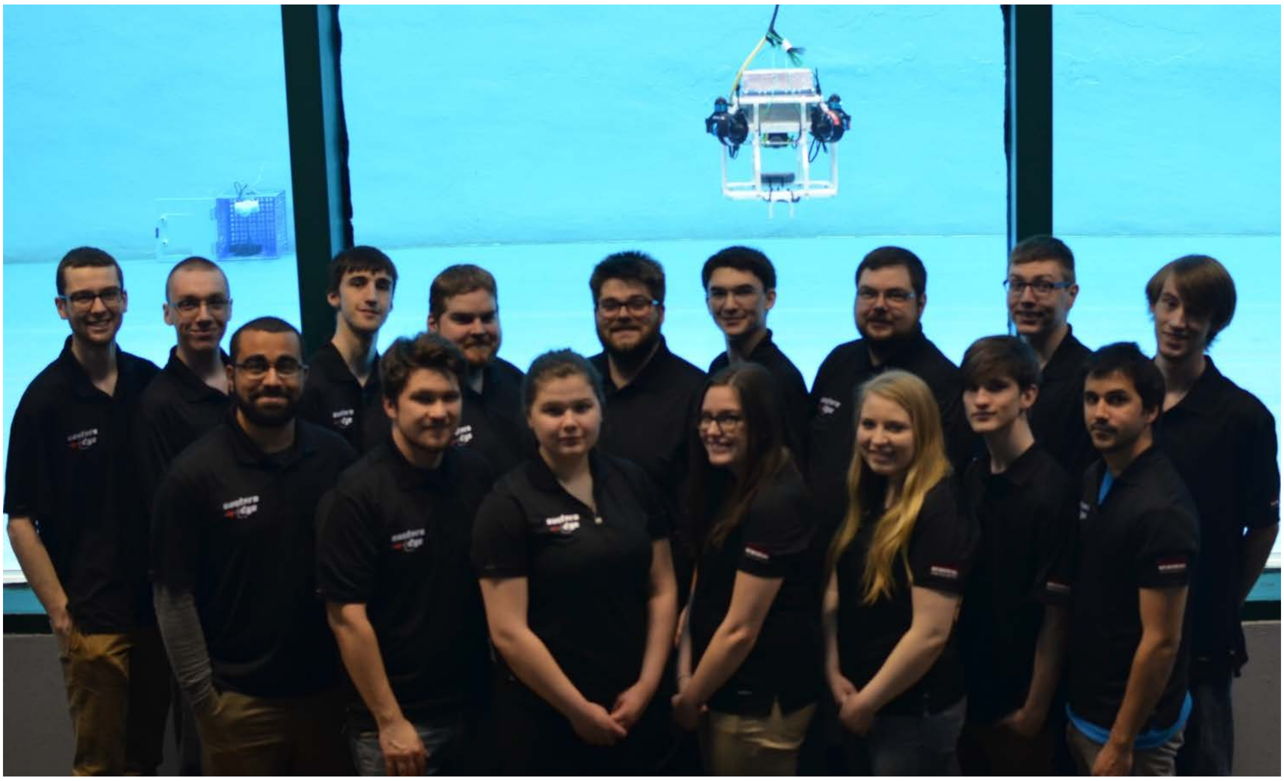

Figure 1: Company Employees & Blue Puttee. Taken at the Marine Institute's Flume Tank
Back (L-R): *Anthony Randell, Christian Samson, Zach Brown, Nick Martin, Adam Pelley, Calvin Gregory, Tybalt Lea, Adam Tremblett, Nick Graham*
Front (L-R): *Whymarrh Whitby, Evgueni Sapojnikov, Keely Lullwitz, Sarah White, Michaela Barnes, Timothy Hynes, Will Glatt*
Missing: *Nathan Ash, Racheal Seymour, Cal Pratt, Halie Murrin, Connor Whalen, Keith Sutherland*

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2.0 Company Overview

2.1. Company Introduction

Eastern Edge Robotics (EER) is a company formed by a multidisciplinary group of undergraduate students from Memorial University of Newfoundland which specializes in developing reliable and efficient products for use in challenging marine environments. The Company prides itself on being at the leading edge of Remotely Operated Vehicle (ROV) technology and community leaders in safety and education.

EER has been a competitor in the Marine Advanced Technology Education (MATE) ROV Competition for the past 14 years. The Company's history includes three first and three second place finishes in the Explorer Class. Most recently at the 2015 competition hosted in the Company's home town of St. John's, Newfoundland & Labrador, EER placed second in a field of over 30 competitors.

This year, the Company is competing for the 2016 MATE contract using an entirely new vehicle, built from the ground up with the challenges of space travel in mind. The vehicle's name, Blue Puttee, is a tribute to the Royal Newfoundland Regiment that fought at Beaumont Hamel in the Battle of the Somme 100 years ago, July 1916.

2.2. Organizational Structure

EER values employing a diverse group of people with a variety of skillsets both technical and non-technical in nature. The Company coordinates itself by discipline in a tiered organizational structure. Figure 2 depicts the organization of the Company's resource allocation and task assignment framework.

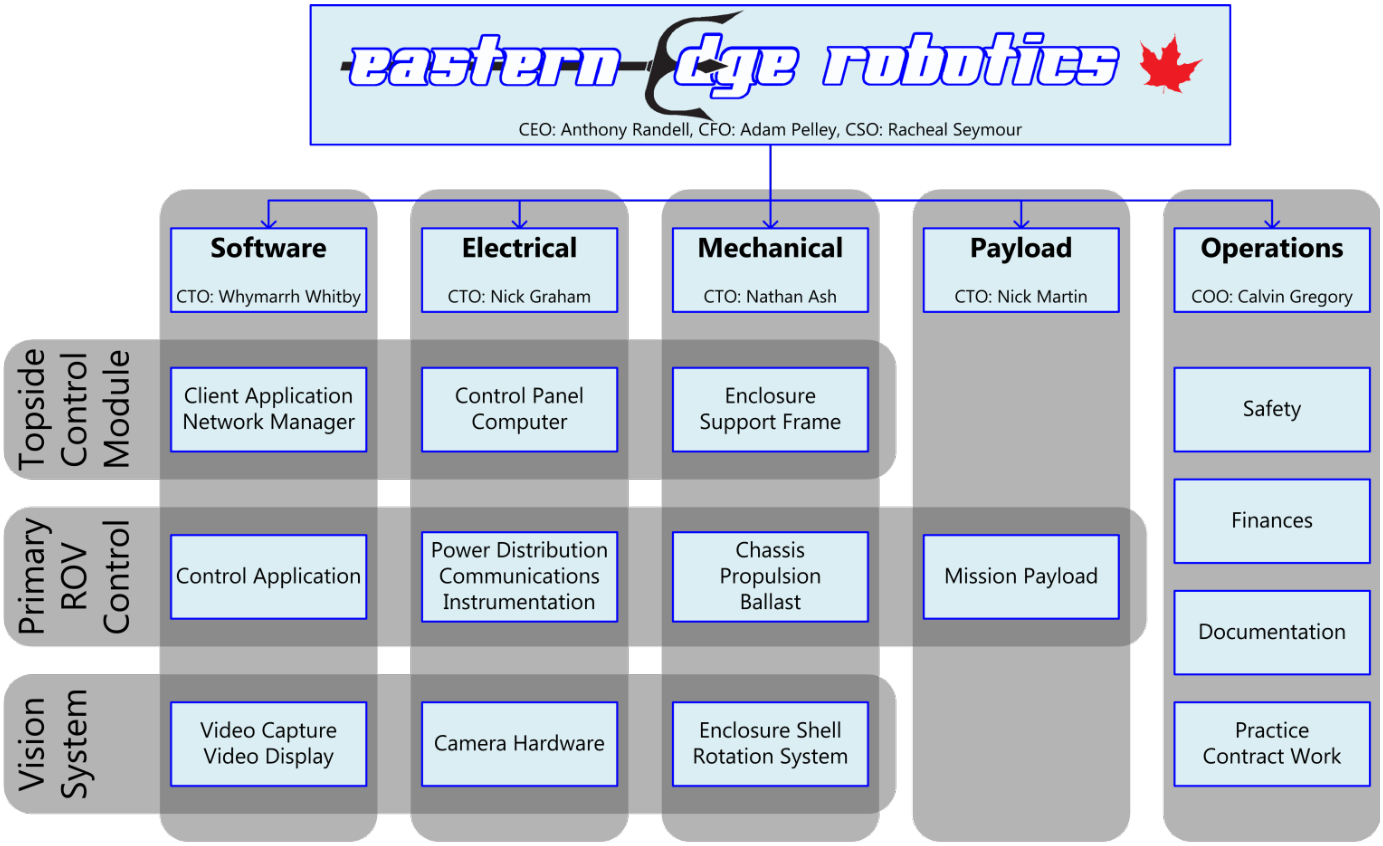


Figure 2: Eastern Edge Robotics Team Assignment Structure

3.0 Logistics

3.1. Project Management

Each of the major vehicle systems are multidisciplinary components requiring coordinated use of both resources and materials. To maximize productivity, EER utilizes an authoritative project management structure. This type of project management is characterized by a strong core of senior managers who have a vision for the project which they share with their teams. Discipline leads and executives work closely together to ensure resource control is optimized by fostering teamwork, delegating projects and sub-projects, and encouraging employees to play to their strengths.

The Company sets short term goals and milestones to keep employees motivated. Experience has shown that achieving a series of smaller goals helps to maintain employee morale over the long term and keep their focus on overarching project objectives. The Company holds debrief meetings after the completion of each major milestone in which contributors can reflect on what went well and what did not. Records of these reflections help to continually improve the Company's product quality and time management practices.

To aid in task planning and resource allocation, the Company utilized an online project management tool called Asana. Asana was used for task assignment and tracking, brainstorming, schedule preparation, and cross-disciplinary discussion. The Company found Asana to be a very useful time management and communication tool, particularly in the early design phase of the project when the Company was not meeting in person as often. In addition to Asana, the software team utilized GitHub. GitHub provides a set of procedures through which software issues are tracked, requests for changes are logged, and revisions to the control software are managed.

The Company also places value in developing the skills of its employees. During this year's orientation period in the fall of 2015, new employees were paired with senior employees within their discipline. This mentoring program was used to familiarize new employees with company standards and safety practices as well as helped develop skills such as Computer Aided Design (CAD) and manufacturing. This year was the second time EER has implemented this mentoring program and the Company has seen great improvement in new employee engagement as a result.

3.2. Scheduling

With an understanding of the challenges in designing and constructing a completely new vehicle, the Company began working on the 2016 vehicle immediately following the completion of the 2015 contract. The Company decided upon project milestones with aggressive deadlines and meetings which began in July 2015, continuing throughout the summer. In preparation for the upcoming contract, the company created a schedule in the form of a Gantt chart with intended start and completion dates which can be seen in Appendix C – Preliminary Project Schedule.

In September the Company held an open house and new member orientation, which lead to an increase in personnel resources. When the 2016 contract briefing was released in September 2015 many of the electrical components had already been purchased and the Company was moving into the detailed mechanical design phase.

By January the Company had completed the vehicle design and were manufacturing or assembling major components. The most significant impact on the schedule was the challenge encountered in manufacturing and sealing custom penetrators to bring cables in and out of the electronics enclosure. Several attempts were required to get an enclosure and penetrator combination that was adequately sealed, negatively impacting the Company's projected flight date by approximately three weeks. The first flight test occurred in mid-March. From that point onward, practice and refinement made up the largest part of the Company's activities.

3.3. Finances

3.3.1. Preliminary Budget

EER Vehicle Budget 2016	
Electrical & Software	$3,997.47
Mechanical & Payload	$3,840.00
General & Administration	$500.00
Total	$8,337.47

Figure 3: Preliminary Vehicle Budget Summary

One of the primary objectives for the 2016 contract was to build a ROV costing far less than previous EER vehicles, whose fair market values have frequently exceeded $25,000 USD. In order to build a low cost vehicle the Company set a budget of $8,500 USD using cost projections based on a preliminary design and estimated component prices totalling $8,337 USD (Figure 3). A weak Canadian dollar hampered the Company's ability to make economic purchases, including the travel budget which ultimately exceeded $30,000 USD (Figure 4).

EER Travel Budget 2016 (14 Students & 3 Mentors)			
Item	Quantity	Unit Price (USD)	Extended Price (USD)
Flights	17	$800.00	$13,600.00
Hotel Room (8 nights, $135.00/night)	10	$1080.00	$10,800.00
Rental Vehicle & Gas	3	$650.00	$1,950.00
Student Contribution	14	$200.00	$2,800.00
Misc. Travel Costs	14	$200.00	$2,800.00
Total			$31,950.00

Figure 4: Preliminary Travel Budget Summary

3.3.2. Project Costing

EER Vehicle Expenditures 2016	
Electrical & Software	$5,161.85
Mechanical & Payload	$825.93
General & Administration	$744.20
Total	$6,731.99

Figure 5: Vehicle Expenditures to 15 May 2016

Blue Puttee Fair Market Value	
ROV Total	$5,078.79
Topside Total	$1465.07
Fair Market Value	$6,543.86

Figure 6: Summary of Blue Puttee's Fair Market Value

The Company was able to keep the total cost of materials purchased ($6731.99 USD) below what was budgeted for the contract, as shown in Figure 5. This is a testament to the careful planning and tracking of expenditures for the 2016 contract, helped by some resource donations. This is a huge success for the Company as it represents the achievement of a major 2016 design objective: to produce an inexpensive vehicle. Two of the largest expenses: the machining of the electronics enclosure and the tether, were provided to the Company at either a discounted rate or free of charge. This significantly decreased the Company's expenditures. The discrepancy between the Mechanical & Payload budget ($3,840 USD) and the expenditures ($826 USD) can be explained by the use of material stock purchased or donated in previous years. The cost over-run on Electrical & Software is attributed to deviations from the preliminary design. The remaining budget was used to purchase spare components and reserve funds for future contracts.

Blue Puttee's Fair Market Value of $6543.86 USD was calculated by considering all the materials required to construct the ROV and the Topside Control Module (TCM). This included items purchased, donated, and discounted. A more detailed fair market value breakdown can be found in Appendix D – Blue Puttee Fair Market Value, a summary of which is shown in Figure 6. A list of supporters can be found in the Acknowledgements section.

EER's travel expenditures ($25,937 USD) were well below the budgeted amount due to the Company's careful planning. A detailed breakdown of these expenditures is shown in Figure 7.

EER Travel Expenditures 2016	
Item	Cost (USD)
Flights (17)	$12,466.18
Hotel Room (10 rooms, 8 nights)	$6,635.40
Rental Vehicles (4) + Gas (estimated)	$1,235.36
Team Funding Recovery (estimated)	$2800.00
Misc. Travel Costs (estimated)	$2800.00
Total	$25,936.94

Figure 7: Summary of 2016 Travel Expenditures

3.3.3.Non-Technical Challenge - Canadian Recession

One major non-technical challenge faced by the Company this year was the Canadian recession. The Canadian dollar performed poorly (compared to the US dollar) over the last year, hitting its lowest value ($0.69 USD) in 10 years during the peak of the Company's purchasing period.

Further compounding the weak Canadian dollar was the low price of oil. As the economy of Newfoundland & Labrador is heavily reliant on oil revenue, many Company sponsors and donors were experiencing difficult economic times. This made funding for the Company difficult to secure.

To overcome this challenge, it became particularly important for EER to budget carefully and manage its expenditures. The Company sourced components from within Canada wherever possible to minimize the impact of the exchange rate on purchases. Furthermore, the low-cost design that EER pursued meant that the effects were not as pronounced as they would have been in prior years.

4.0 Safety Culture and Practices

4.1.Safety Philosophy

Safety is the premier concern of EER. The Company has a number of policies in place to maintain an open discussion on best practices to foster an effective safety culture. Hence, this enforces the safety philosophy: nobody gets hurt. EER believes that all employees are entitled to a safe work environment, which the Company implements through a variety of mediums.

4.2.Operational Safety Practices

All of EER's operations begin with a toolbox talk, a discussion which includes the completion of a Job Safety and Environment Analysis (JSEA), and an Operational Safety Checklist (Appendix A – Operational Safety Checklist). This discussion encourages employees to not only work more safely, but also more effectively. The Company's JSEA and Operational Safety Checklists were developed by a group of employees, and approved and verified by the Chief Safety Officer (CSO). All Procedures are referenced and updated when safety concerns arise, to ensure that all potentially harmful situations are addressed.

Accompanying toolbox talks, the Company has a common practice to pair up senior employees with inexperienced employees to run through hazards and safe practices associated with all job tasks. EER's on-boarding system allows employees to discuss safety concerns in a comfortable one-on-one setting, fostering open communication and effective learning.

4.3. Safe Work Observation Program

The Safe Work Observation Program is a set of operating procedures and a form (Appendix B – Safety Observation Form) which employees fill out when concerns related to workplace safety arise. This can include commendations for exceptional safety awareness and hazard or incident observations. The Safety Observation Forms enable the Company to track potential safety concerns and revise safety procedures as required. The forms are reviewed regularly by the CSO and are discussed during weekly meetings. These meetings also include a safety moment and the completion of a JSEA for any work to be completed that day. Open discussions concerning safety are encouraged by the Company, and treated with utmost respect.

4.4. Vehicle Safety

Blue Puttee has been designed and manufactured with safety in mind and adheres to all specifications outlined in the 2016 contract's call for bids. Some of the key safety features include a 40 Amp main circuit breaker, software-based pre-dive checklist, hardware and software kill switches, ROV lights indicating when the vehicle is safe to touch, thruster guards, and warning labels on power connections and moving parts.

5.0 Design Rationale and Vehicle Systems

5.1. Design Philosophy

In order to provide the best experience for the client the Company employs a user-centered design philosophy when developing products. User-centered design is a concept which places paramount importance on the user experience, hiding much of the inherent technical complexity and providing an easy-to-use interface with which the pilot interacts. To successfully achieve this, the vehicle must be stable and move naturally, the payload must be easy to use, and the controls must be intuitive and logical to the pilot. By keeping the user-centered design philosophy in mind, EER has developed a product which is not only capable of completing the 2016 contract, but is a pleasure to operate.

5.2. Major Constraints

The 2016 call for bids from MATE presented EER with a set of strict constraints to which the vehicle had to conform. As this year's contract involves a mission to Jupiter's moon Europa, size and weight were at a premium. This led the Company to design an entirely new vehicle, using none of the components from previous years' vehicles. The constraints set by the MATE Center were:

- The vehicle's largest face must fit through a 580 millimeter diameter hole.
- The vehicle and tether combined must weigh less than 17 kilograms.

Blue Puttee is the smallest and lightest of any ROV ever produced by EER, easily fitting inside the envelope outlined in the call for bids (Figure 8).

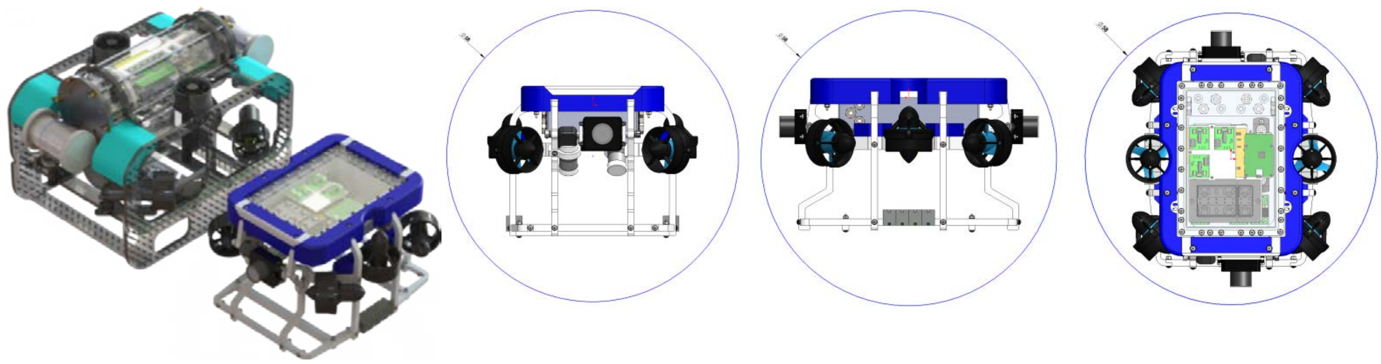


Figure 8: Size Illustration of Blue Puttee Compared to 2015 Vehicle and 58 cm Envelopes

5.3. Chassis

Blue Puttee's chassis design is structured around the size and weight restrictions imposed in the call for bids for the 2016 MATE contract. As such the design philosophy was to use the lightest material practical and to design a structure around the major components: the electronics enclosure and the thrusters (Figure 9). The design progressed from an initial quad directional aluminum structure to a bi-directional skeletal structure manufactured from high density polyethylene (HDPE). HDPE was chosen over aluminum and polycarbonate (used in previous years) for its low density (0.97 g/cm^3 compared with 1.22 g/cm^3 for polycarbonate), lower cost (approximately half that of polycarbonate), and ease of in house manufacture using a Computer Numerical Control (CNC) router. The total mass of the chassis itself is 1783 grams.

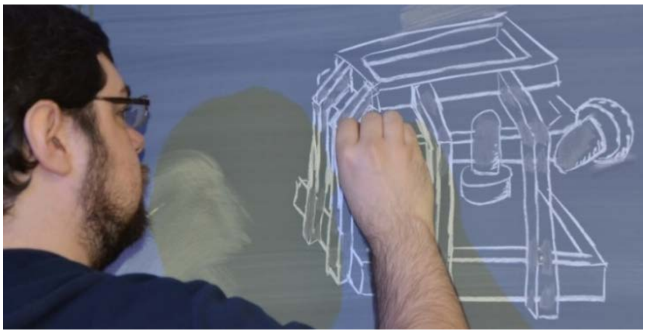


Figure 9: Tybalt Lea Working on an Early Chassis Design

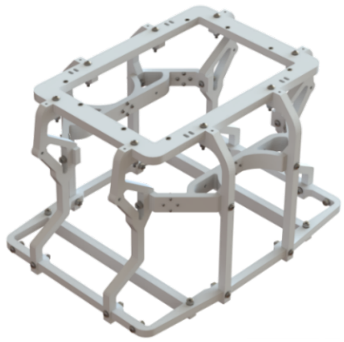


Figure 10: Rendering of Blue Puttee's Chassis (Revision 2)

The Company constructed and tested two chassis in preparation for the 2016 contract. The first was a prototype designed as a proof of concept for size, weight and vehicle stability. Following the prototype, modifications were made to make the final chassis easier to manufacture and accommodate features such as camera rotation mechanisms and payload (Figure 10). Blue Puttee is capable of bi-directional operation, meaning the fore and aft of the vehicle are interchangeable with a software control reversal, allowing for more payload space and improved manoeuvrability.

5.4. Stability

Blue Puttee is trimmed using fixed floatation and ballast. Static stability is achieved by placing the floatation at the top and ballast at the bottom. This keeps the Center of Buoyancy (CB) above the Center of Gravity (CG) (Figure 11). Dynamic stability is achieved by aligning the Center of Thrust (CT) with the CG, enabling the vehicle to travel at high speeds while remaining level. Blue Puttee uses closed-cell polystyrene coated in an epoxy resin for floatation. This was chosen for its low density, low cost, and ease of machining on the Company's CNC router. For ballast, the Company chose to use a system of modular lead weights manufactured in house. Lead was chosen for its high density and low cost. The modularity of the system enables the vehicle to be trimmed quickly and easily during operations to ensure optimal stability under a variety of payloads.

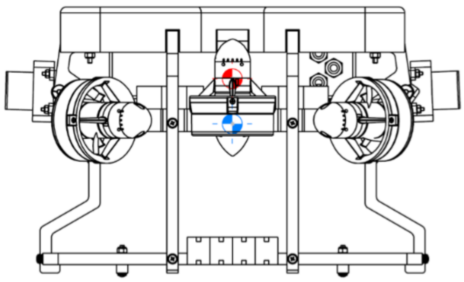


Figure 11: Vehicle Stability Diagram

5.5. Propulsion

Due to the size and weight restrictions, many discussions were held within the Company about the number and configuration of thrusters to use. To evaluate different options, the Company conducted mass calculations for a variety of thruster configurations. EER initially intended to use eight thrusters (four vertical and four lateral) providing six degrees of freedom (heave, surge, sway, yaw, pitch, roll). However, it was determined that six thrusters would enable EER to best meet the size restrictions while also allowing for adequate manoeuvrability.

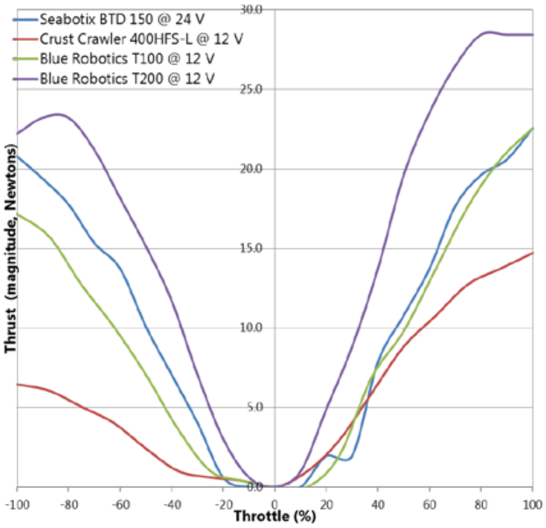


Figure 12: In-House Thruster Testing Results

In a further effort to simplify and save weight, the Company researched purchasing new thrusters which could be more easily integrated into the system from both a hardware and software perspective. Commercial thrusters were chosen as they offer higher thrust than any the company could manufacture, and the cost per unit was only slightly greater than estimates for in-house manufactured thrusters. The results of bollard pull tests conducted by the Company enabled an evidence-based decision on which thrusters to purchase (Figure 12). The Blue Robotics T200 thrusters outperformed all other models tested, including the Seabotix thrusters used in previous contracts.

Blue Puttee uses six Blue Robotics T200 brushless thrusters. These thrusters are 80% cheaper and 60% lighter than those used for several years by EER. There are two vertical thrusters, one port and one starboard. The four lateral thrusters are vectored at 45^0 and in opposition to each other for control symmetry, a configuration used previously by EER to great success (Figure 13). This configuration gives Blue Puttee five degrees of freedom, offering surge, sway, and yaw in the horizontal plane and the ability to roll and heave in the vertical plane. Each thruster has a maximum power consumption of over 180 Watts, providing a top speed in excess of one meter per second horizontally and 0.6 meters per second vertically.

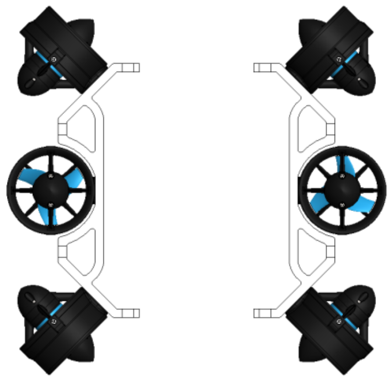


Figure 13: Thruster Configuration

5.6.Cameras

For 2016 EER decided to move away from the camera system design used in past years. These cameras were large, complex and prone to failure. This year, the Company has opted to use Raspberry Pi single board computers with integrated cameras, enclosed in an innovative 3D printed shell (Figure 14). This creative enclosure solution was designed, manufactured and assembled in-house, then waterproofed using potting compound.

The rotation mechanism for each camera is provided by a geared DC motor (Figure 15). These were chosen because they are much easier to waterproof, offer higher torque, and are less expensive than servos. Blue Puttee has two cameras onboard: one on the fore of the vehicle and one on the aft. Each camera is capable of rotation exceeding 180^0 enabling each camera to see both payload braces on the vehicle. Because each camera can look at both payload braces the pilot can perceive depth. This improves user experience in line with the Company's user-centered design philosophy as it makes aligning payload tools much easier.

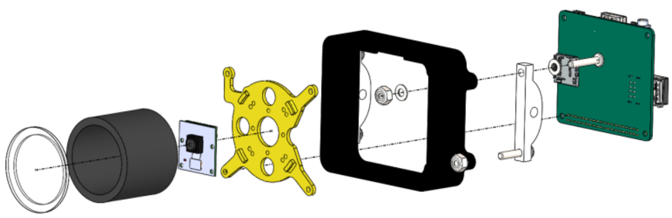


Figure 14: Exploded view of Blue Puttee's Camera Assembly

In previous years cameras used by EER were difficult to interface with software as the video was uncompressed. This caused memory overloads on the control software resulting in system crashes. The new camera system on Blue Puttee has many advantages from a software integration point of view. The Raspberry Pi and camera module were chosen because of their low cost, availability and excellent community support. The video is encoded and transmitted over Ethernet for the TCM to decode and display. Encoding the video means it does not require as much network bandwidth, keeping latency and communication errors to a minimum. The cameras also offer improved image processing and can be easily optimized for the desired use (low latency, high quality, contrast, etc.).

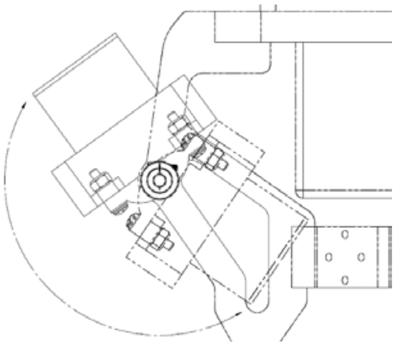


Figure 15: Camera Rotation Mechanism

When selecting cameras EER maintained the user-centered design philosophy and chose cameras and lenses that provide the best image to the pilot. For this reason, the Company chose cameras capable of streaming 1080p video and taking five megapixel still images for precise image analysis and measurement purposes. The lenses offer a field of view of approximately 90^0 in water.

5.7. Electronics Enclosure

EER has completely rethought electronics containment for the 2016 contract. In previous years, the Company had used large acrylic cylinders to house electronics, using both radial and axial O-rings to seal the enclosure. These cylinders, while easy to manufacture, were very inefficient. Their shape meant that electronics could not be packed densely and their limited flat surface area (found only on the end caps) made it difficult to place cable penetrations.

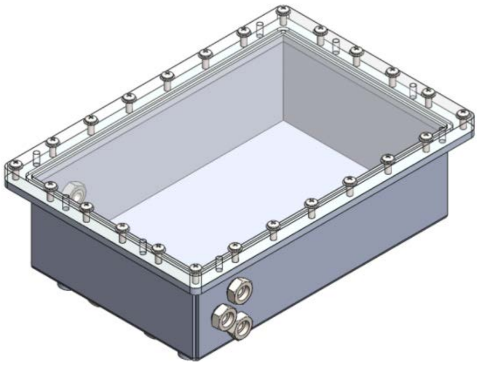


Figure 16: CAD Model of the Enclosure

Blue Puttee's electronics enclosure, shown in Figure 16, was a joint design between the electrical and mechanical groups. The collaboration resulted in a product that fits the needs for both groups while maximizing technical considerations for a critical piece of equipment. As EER lacks the welding facilities required to fabricate the enclosure, it was provided at a discounted rate by Memorial University Technical Services and the material was donated by Steel Fab Industries.

The enclosure is a rectangular prism designed to house multiple layers of electronics, offering a more efficient use of space. The external dimensions are 306 x 210 x 95 millimeters with a mass of 1568 grams. Aluminum was chosen for its heat dissipation properties, ensuring optimal heat removal from the more densely packed components within the enclosure. It also has a lower density than other commonly used metals such as stainless steel, reducing the enclosure weight. The lid is made of polycarbonate enabling visual inspection of both the O-ring seal and the electronic components inside, decreasing troubleshooting time. The penetrations are seal bolts, customized in-house by EER using a lathe. These penetrations were chosen over traditional wet-mate bulkhead connectors because they are far lighter and easier to pack tightly. All penetrations are on the bottom and sides of the enclosure, enabling ease of installation of the connectors and lid.

5.8.Electronics

Previous EER vehicles contained many different voltages, communication protocols, and expensive pieces of equipment. This meant that troubleshooting was a long and difficult task with the potential for expensive replacements. Blue Puttee's all new onboard electronics system marks a great step forward for the Company (Figure 17).

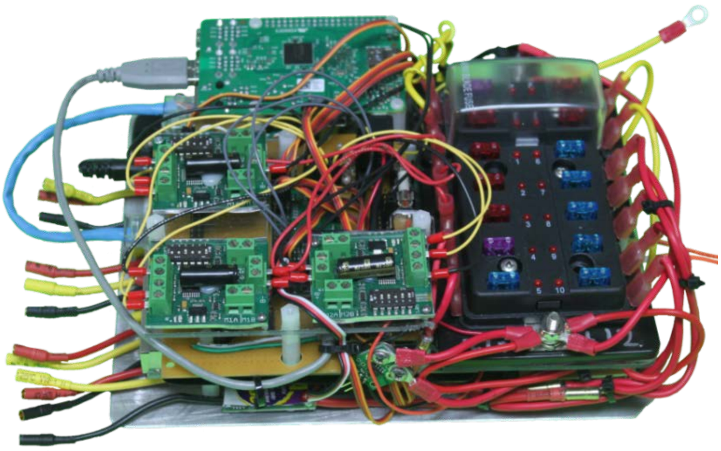


Figure 17: Onboard Electronics Assembly

Commercial components were researched extensively to find solutions which were low cost, easy to integrate, and reliable. In keeping with the user-centered design philosophy, the system was optimized for simplicity of understanding and troubleshooting (Appendix E – System Integration Diagram (SID)). To achieve this goal, the vehicle utilizes three onboard voltages, compared to five in previous years. Additionally, the total number of communication hardware types was reduced from seven to two. All these simplifications were made while also improving the overall capabilities of the system.

Blue Puttee's primary power is provided by one 48 Volt-to-5 Volt DC/DC converter and three parallel 48 Volt-to-12 Volt DC/DC converters. The system is capable of supplying over 1200 Watts to the vehicle's thrusters, nearly double that of EER's 2015 vehicle. Further, using three primary DC/DC converters allows continued vehicle operation with minimal impact for up to two converter failures.

The communication backbone of the system is a Gigabit Ethernet network used to link the TCM to the primary control unit - a Raspberry Pi single board computer - and to each of the cameras. The onboard network switch has two spare ports for additional cameras, control units, or other devices, making expansion simple.

In an effort to stay on budget and improve reliability, components were selected for both their low cost and availability. In 2015, the most expensive component in the electronics system was over $1500. This year, it is less than $75. The low price point enables EER to carry many spares with few financial ramifications. If a spare is not on hand, the longest lead time of any component is approximately one week, meaning downtime is minimized and expense to the client is low.

To further improve the user experience, Blue Puttee features a wide variety of onboard diagnostics and instrumentation to give the operator a complete understanding of how the vehicle is performing. Internal and external pressure and temperature, voltages and currents, and onboard computer performance are just some of the metrics EER uses to ensure vehicle performance.

5.9.Tether

Blue Puttee's tether was designed by EER and fabricated and donated to the Company by Leoni-Elocab. The tether is eight millimeters in diameter and 25 meters long, an appropriate length for the 2016 contract (Figure 18). It weighs 63.6 grams per meter of length for a total weight of 1591 grams. An integrated jacket makes the tether neutrally buoyant, simplifying tether management both in and out of water. It contains two copper conductors which provide power to the ROV at 48 Volts, and two optical fibres used to carry communication to the ROV. EER uses optical fibres for their high bandwidth, superior reliability, electrical noise immunity, and lower mass when compared with copper alternatives. Blue Puttee's new tether was selected over last year's stock which consisted of two copper conductors, eight optical fibres, and an internal pneumatic line (Figure 19). This year's tether did not require the extra optical fibres and pneumatic line due to system simplifications, enabling a 60% weight reduction for the same length.

Figure 18: 2016 Tether

Figure 19: 2015 Tether

5.10.Topside Control Module

EER has developed a new integrated TCM for the 2016 contract to simplify system deployment and transportation. The choice to develop a new TCM was recognised as a significant financial commitment by the Company. It was justified as this TCM will be suitable for use beyond 2016, reducing expenditures over time. To help decrease costs the Company repurposed an enclosure for the TCM; previously it had been used to hold miscellaneous items when travelling to competitions. Its size, durability, and built in wheels makes it ideally suited for its new purpose.

The all new TCM was designed with the user in mind. It contains a desktop computer running the Ubuntu operating system from which the ROV is controlled. The large, integrated monitor gives the pilot a view of all the ROV's cameras as well as information such as thruster power settings and instrumentation readouts. This TCM was also designed with expansion in mind, so there is ample room within the enclosure for future components.

The TCM contains an interface panel with buttons, sliders, and dials (Figure 20). The choice to use physical inputs for the system follows the user-centered design philosophy. Pilots are better able to 'feel' the settings of the vehicle with tactile inputs as opposed to graphical inputs, allowing the pilot to look away from the video feed mid-flight. The interface panel is modular, meaning that each of the six modules can be moved around or replaced to conform to the preference of the pilot.

The TCM also contains many of the ROV system's safety features. These include a 40 Amp circuit breaker less than 30 centimeters from the power source, a ground fault interrupter (GFI) on the shore power input, voltage and current monitoring devices, and software emergency kill switch. Additionally, having all topside components contained within a single enclosure while still physically isolating the ROV power from shore power greatly decreases the potential for hazards during operations. The simplified TCM system has greatly decreased the setup and teardown time during operations, and makes transportation to and from the operation station much safer and simpler.

Figure 20: The TCM's Interchangeable Interface Panels

5.11.Software

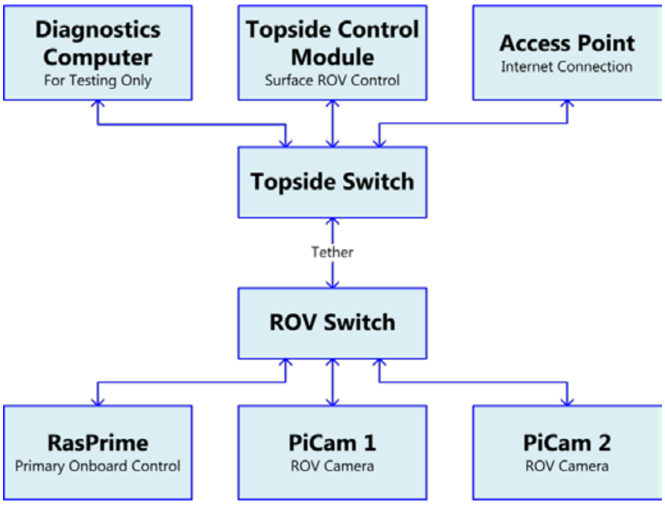


Figure 21: ROV Ethernet Network Topology

With the vehicle's electronics redesigned to include multiple onboard computers, the control software for the vehicle was rewritten from the ground up to optimize for the new components. Due to the number of onboard computers – two Raspberry Pi single board computers with camera modules and a Raspberry Pi primary control unit – the control software is distributed across the devices, forming a network of devices communicating via Ethernet (Figure 21, Appendix F – Software Flow Diagrams). This network also enables multiple users to connect to the system, meaning software updates can be performed without incurring downtime. One particularly innovative feature is that the network is capable of connecting to the internet, enabling remote monitoring and operation.

The control software was written in the Java programming language, a widely used and well-supported language within the software development industry. Java is familiar to many of the developers within the Company and was the best choice for developer onboarding. Additionally there exist many available open-source Java libraries that allow for ease of hardware integration, allowing the software team to focus on the Company's core business and ensure that the design philosophies of simplicity and user-centered design were followed. These libraries aided in the step-by-step implementation of the control software, allowing major features to be implemented first.

5.11.1.Distributed Communication

To abstract away the distributed and asynchronous communication of the control software, EER designed a message system that broadcasts messages to all computers on the network at once. The message system is the primary communication method of the control software and is used to relay data from the TCM to the vehicle as well as intra-vehicle. Broadcasted messages include thruster speed values, sensor data, and power usage of the ROV. Because each message is sent to the entire network, computers can select and filter the messages of interest. The decision to use the User Datagram Protocol (UDP) for the transmission of messages instead of the Transmission Control Protocol (TCP) was based on UDP's lower latency and the Company's ability to strictly control traffic flow over the network, making the typical advantages of TCP (error checking and redundancy) unnecessary. UDP requires explicit message ordering and duplicate prevention. To implement this the Company attaches logical clocks to each of the messages and orders them at their destination.

5.11.2.Device Inputs and Outputs

The vehicle's primary control unit interfaces with a Pololu Maestro controller to handle all physical inputs and outputs. This choice allowed for reduced complexity when interfacing with multiple devices and was built on knowledge from previous years using the same controller series. Because the Company has worked with similar devices before, past versions of the control software were used as a reference for implementation of communication. This fast-tracked the development of a core component of the vehicle. Using the Maestro for device inputs and outputs enables ease of hardware expansion using spare channels, each of which can be quickly configured as required.

5.11.3. Video

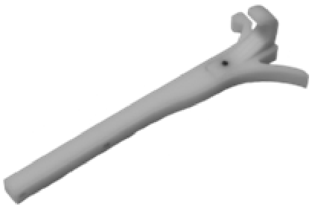
Blue Puttee's onboard cameras run the same control software as the primary control unit. These cameras broadcast messages such as onboard sensor data (e.g. voltage, temperature, clock frequency) to the TCM. Additionally, the cameras run raspivid, an application used to stream video to the TCM. The TCM uses the open-source media player, mpv, to display and manipulate the video feed as required. The Company performed benchmarking tests on a number of alternative players and found that mpv had the lowest latency.

5.12. Payload

For many years, the backbone of EER's payload capabilities was an onboard pneumatic system. However, to comply with the newly introduced size and weight restrictions the Company did a cost benefit analysis of different approaches to payload. During this analysis the payload team reviewed pneumatic, hydraulic, electric, and passive payload options. The conclusion of this investigation was that the benefit provided by active systems would not outweigh the additional weight and system complexity. Additionally, the payload team researched and prototyped custom solenoids, but the performance was too poor to pursue further. For these reasons, Blue Puttee's payload is entirely passive, with the exception of one electric motor.

Object-Manipulating Easy Grab Attachment (O-MEGA): A versatile tool which comes in a variety of sizes, the O-MEGA is used to quickly and effectively pick up and transport many objects. This tool is completely passive, meaning that no actuation is required to secure or remove objects, relying instead on vehicle movement. This tool can also be mounted on a motor to enable manipulation in multiple orientations, such as installing bolts.

Bident: Resembling the Company's trident logo, the Bident is able to transport objects similar to the O-MEGA. It is used to pick up and install the flange and wellhead. This tool is easily manufactured to fit the size of the object being handled.



Simple Puller Opener Rotator Key (SPORK): Much like its namesake, the SPORK is a multipurpose tool used to pull, open, or rotate anything an ROV may run into. Created out of the necessity to keep tools simple and compact, the SPORK is used in almost every part of operation. Much like the O-MEGA, this tool is completely passive.

Not Often Observing Temperature (NOOT): NOOT is an external temperature sensor designed specifically to measure the temperature of thermal vents on the sea floor. Its design allows for the pilot to easily position the sensor over the vent.

Carbon Coral Collector: A lightweight, but strong tool, the Carbon Coral Collector is used to retrieve coral samples. It has a simple design, but is very effective in operation. The tool's carbon fibre construction helps minimize the overall weight of the payload.

As the addition of tools would increase the overall dimensions of the vehicle, the Company had to come up with an easy and fast solution to install tools during the demonstration setup. A quick-attach payload brace (Figure 22) was designed, enabling tools to be fastened in place with the use of wing nuts, significantly decreasing setup time required. These braces placed on each end of the ROV allow tools to be moved during testing so the pilot can determine the optimal tool locations.

Figure 22: Blue Puttee's Quick Attach Payload Brace

Due to the large size of the Payload team, payload options were brainstormed and prototyped rapidly, allowing the Company to evaluate many different designs. Often tools would go from concept to testing in only a few hours. The use of scrap material for these prototypes ensured that there was no significant cost to the team when exploring payload options, which greatly decreased the expenditures on plastic material stock.

6.0 Lessons Learned

6.1. Interpersonal Skills Gained – Cross-Disciplinary Coordination

EER grew adept at optimizing task delegation over the course of this contract, particularly in the area of multidisciplinary work. As many ideas were shared amidst the Company, communication became a key factor in delivering projects in a timely manner. The personnel organization strategy employed by the Company allows employees to interact constructively with colleagues from their own discipline as well as in other disciplines and achieve multidisciplinary goals more effectively. EER's tiered management structure demands effective communication and task distribution amongst members in the interest of efficient workflow. Interdisciplinary collaboration is not always simple, as it often requires more explanation of techniques or ideas than would be necessary when speaking with a fellow discipline team member. The Company avoided miscommunications and work overlap by directing initial task delegation through upper management. This approach allowed for the most efficient allocation of company resources; managers were aware of the ongoing projects of their team members and could reassign resources based on availability and suitability.

6.2. Technical Skills Acquired – Enclosure Design & Fabrication

EER developed a new electronics enclosure for the 2016 contract. The enclosure was made of aluminum and required complex bending and specialized welding. In comparison to previous years where all of the components used on the vehicle were manufactured by the team, the new enclosure design required additional knowledge and equipment. The Company does not have the facilities to fabricate such a part in-house, so the mechanical group had to familiarize themselves with the relevant fabrication drawing standards. The manufacturing of the Company's design could then be outsourced to a third party, Memorial University Technical Services.

6.3. System Testing & Troubleshooting

During the development of Blue Puttee, the Company implemented vehicle systems in stages. This allowed the various teams to focus on one aspect of the vehicle at a time before moving on to additional features. The vehicle's first bench test was completed in January 2016 which established the functionality of the thrusters and cameras, the core systems of the vehicle. Following this, features were implemented sequentially based on priority. This continual system integration allowed the vehicle to be used for practice while newer features were developed and implemented, ultimately leading to a more effective use of personnel resources and time.

EER's approach to troubleshooting is 'one thing at a time'. This follows the traditional scientific method whereby only one variable is changed while all others are kept constant. In this way, the Company is able to quickly focus in on the source of the problem and work to resolve it. One such example of this troubleshooting method was employed in decreasing the camera latency. The software team systematically modified various settings for the onboard pre- and post-processing of the video being captured (frame rate, resolution, encoding method, etc.) to determine which configuration provided the lowest latency on the camera. Following that, the team moved on to the topside video decoding and display where they took the same approach to determine the most optimal solution. Through this process, the team was able to lower the latency from over one second to approximately 150 milliseconds, no longer noticeable to the pilot.

6.4. Technical Challenge – Custom Penetrators

The greatest technical challenge faced by the Company this year was the move from commercial wet-mate connectors to in-house manufactured penetrators. These custom penetrators, which are hollowed bolts with a sealing O-ring, are the means by which electrical cables enter and exit the electronics enclosure and were chosen for their lower weight and size than the alternatives. Though commercially available cable penetrators exist, they were not large enough for many of Blue Puttee's cables. The Company elected to machine their own on a lathe (Figure 23).

Figure 23: Will Glatt Machining Penetrators

When the Company pressure tested the electronics enclosure with these machined bolts in place, many of them leaked. Upon investigation, it was determined that the aluminum used was too soft, becoming easily dented. The O-rings the Company had made were also too small in cross sectional diameter to provide an adequate seal. Further refinement attempts were met with little success and consistency was a challenge as the penetrators were manufactured manually on a lathe.

While searching for a solution to the issue, the Company was able to source stainless steel seal bolts (Figure 24). These bolts are purpose-made to seal holes in high-pressure enclosures. The Company drilled out the center and shortened these bolts to the desired length so that cables could be inserted and potted, creating a suitable penetrator (Figure 24). This required far less manufacturing time and resulted in a more reliable seal.

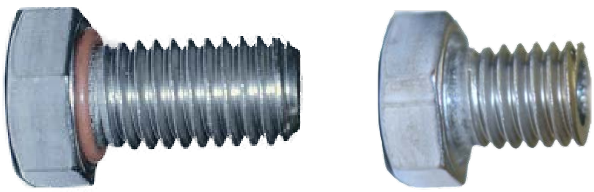


Figure 24: Comparison of Seal Bolts Before (left) and After (right) Modification

6.5. Future Improvements – Improved Quality Management

During the completion of work for the 2016 contract, it became apparent to managers that there exists a potential for improvement in Company efficiency through the implementation of a formal Quality Management System (QMS). During debriefs, it was often noted that projects required multiple prototypes or design revisions in order to achieve the desired end product. This negatively impacted expenditures and project timelines.

A QMS would involve appointing a Quality Manager who would be responsible for developing and enforcing Company standards. The procedures implemented in the QMS would focus on a design review process with appropriate sign-offs, project tracking, documentation, and record keeping.

Though there exist informal quality management systems within each discipline, a centralized QMS with a dedicated manager will help to improve interdisciplinary coordination and help eliminate cost overruns and maintain schedules.

6.6.Reflections

Departing Employee - Will Glatt

It is difficult to describe what I have taken away from Eastern Edge Robotics. For three years it has been a means of applying what I have learned in the classroom, a source of continual challenges, and a creative outlet. It enriched my undergraduate education by providing an immersive and interdisciplinary technical environment in which I have honed my skills as a technologist.

What I have found most valuable are the unplanned lessons which cannot be formally taught. I have first-hand experience in assessing project timelines, identifying critical paths, and working in a diverse and technical environment. These experiences have aided me in job interviews with technology based organizations. I feel that I would not be the able technologist I am today without the wisdom and skills I have developed through the MATE Competition.

New Employee – Keely Lullwitz

After moving halfway across the country to start my post-secondary education, I joined EER this year without knowing anything about underwater vehicles. Being a first year in the Remotely Operated Vehicle Technician program, I was eager to obtain experience that would help me with my studies.

Through EER I have learned valuable skills such as patience, communication, and problem solving. Previously having no experience in mechanical, software, electrical, payload, or piloting, senior mentors were eager to help me learn. Piloting was intimidating, but through practice and tool evolution, my piloting techniques have improved. Collaboration with other team members on the tool design process has allowed me to contribute to the ROV's payload from a piloting perspective. My knowledge of the components inside ROVs has also improved; even with smaller scale vehicles, the same concepts are applied to work class vehicles, greatly helping my studies.

7.0 Acknowledgements

EER would like to thank the following organizations for their support in the development of Blue Puttee, Company travel to Houston, and of the MATE ROV Competition both regionally in Newfoundland & Labrador and internationally.

- Asana: Free Accounts
- GitHub: Free Code Hosting
- Government of Canada: Monetary Donation
- Government of Newfoundland & Labrador: Monetary Donation
- Leoni-Elocab: Donation of Fibre Optic Tether
- Marine Institute of Memorial University: Monetary Donation and Use of Facilities
- Memorial University Faculty of Engineering: Monetary Donation
- Memorial University Faculty of Science: Monetary Donation
- Memorial University Faculty of Business Administration: Monetary Donation
- Memorial University Technical Services: Discount on Enclosure Machining

- mpv: Open Source Video Player used to Display Video on TCM
- OpenJDK: Open Source Java Runtime
- Raspbian: Open Source Operating System used on Raspberry Pis
- Solidworks: Donation of Software Licences
- Steelfab Industries Limited: Donation of Stock Material
- Ubuntu: Open Source Operating System used on TCM

Finally, the Company extends a heartfelt thank you to our mentors Paul Brett, Joe Singleton, Jai Ragunathan, Clar Button, and Craig Bulger for their time, administrative support, and unwavering encouragement.

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Appendix A – Operational Safety Checklist

Safety Checklist

Memorial University, St. John's, Newfoundland and Labrador, Canada
MATE International ROV Competition 2016, Explorer Class

JSEA Completed? □ Yes □ No Date Completed ______________

Employees Involved: ______________________________

____

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Pre-Mission Safety Checklist	
Complete?	Task
	Tether is neatly coiled and clipped
	Topside Control Module Main Circuit Breaker is in 'OFF' position
	DC Power In-Line Circuit Breaker is in 'OFF' position
	Topside Control Module is closed and locked with no wires loose
	Deck Crew is wearing Eye Protection, Personal Floatation Devices and Work Boots

Teardown Safety Checklist	
Complete?	Task
	All power sources safely powered off and disconnected
	Tether is neatly coiled and clipped
	Excess water removed from vehicle
	Topside Control Module is closed and locked with no wires loose

Operational Safety Hazards
No hands on vehicle without software locked
No excess tether left uncoiled on deck
Be cautious of slip hazards generated by water from vehicle, tether, etc.
Keep wet objects/personnel away from Topside Control Module
Any cabling or connections should be both secure and tidy
Be cautious of slip hazards generated by water from vehicle, tether, etc.
Use proper lifting techniques when carrying equipment from work area

Appendix B – Safety Observation Form

Safety Observation Form

Memorial University, St. John's, Newfoundland and Labrador, Canada

MATE International ROV Competition 2016, Explorer Class

Observer: ______________________________ Date of Occurrence: _______________

Employees Involved: ____

Commendation: ☐ Observation: ☐ Incident: ☐

Description:

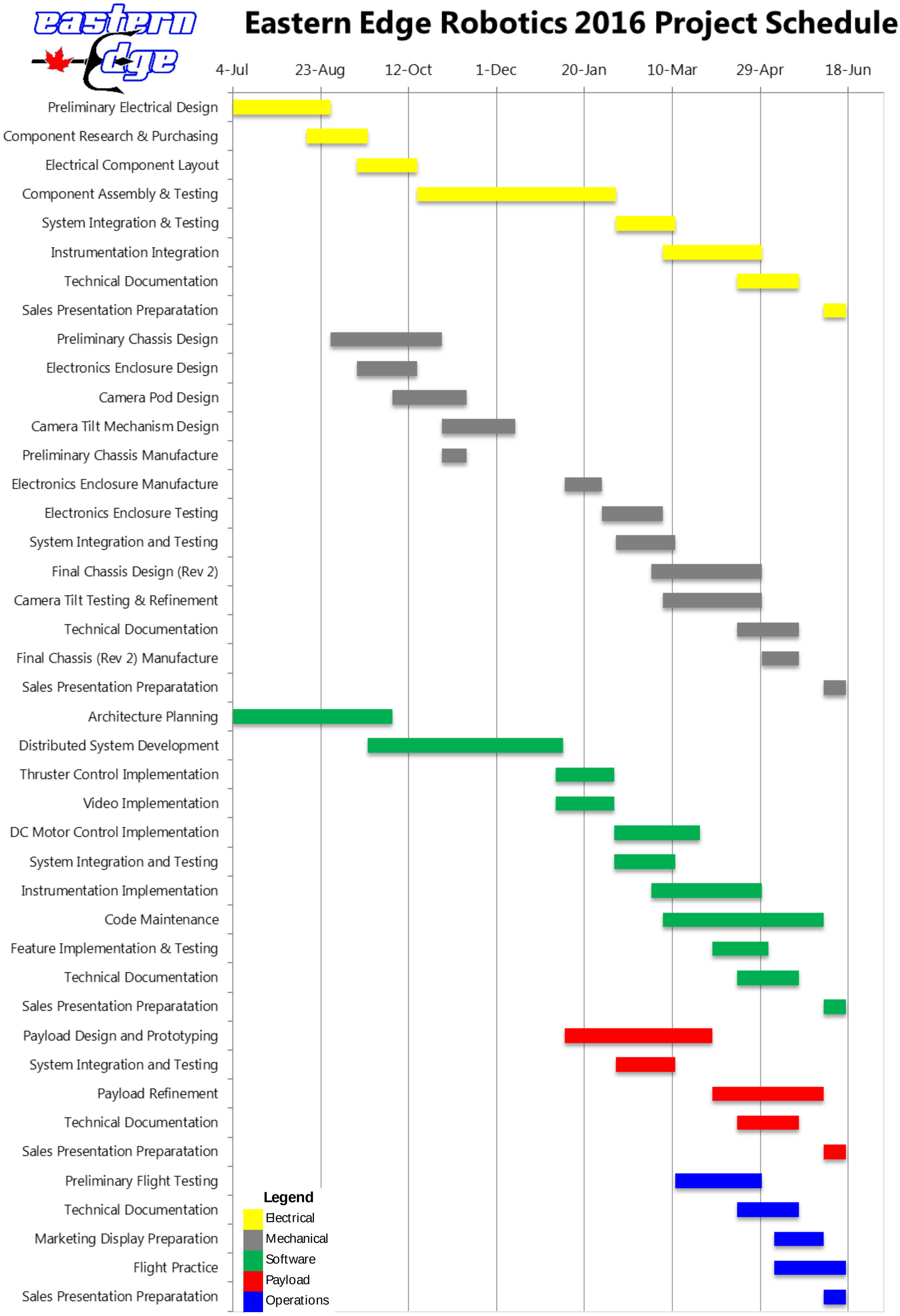
Suggested Course of Action:

Follow Up Tasks (to be completed by CTO lead and Safety Officer):

Safety Officer Sign-Off: _________________

Additional Comments:

Appendix C – Preliminary Project Schedule



Appendix D – Blue Puttee Fair Market Value

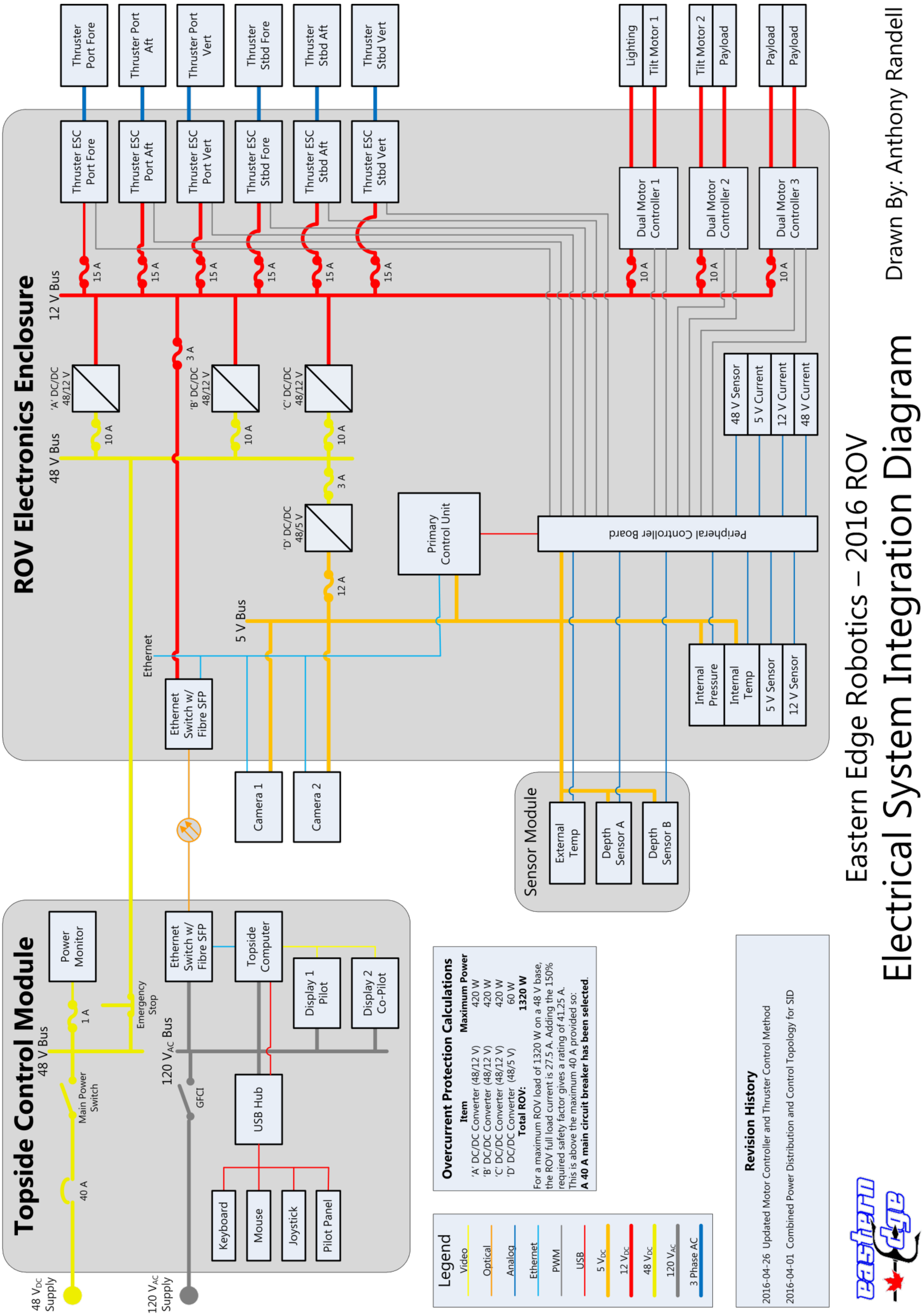
ROV 'Blue Puttee' Fair Market Value

ROV				
Item	QTY	Price Each	Ext. Price	New/Used
Thrusters + ESCs	6	$214.91	$1,289.49	Purchased
Electronics Enclosure	1	$1,062.02	$1,062.02	Discount ($336)
Tether (25 m)	1	$581.40	$581.40	Donated
High Density Polyethylene (1/4", 1/2", 1" sheet stock)	1	$385.70	$385.70	Re-Used
DC/DC Converters (12 V, 5 V) and PCBs	4	$61.86	$247.44	Purchased
Camera (Board, Lens, Enclosure. Rotation Mech.)	2	$121.44	$242.88	Purchased
Polycarbonate (1/8", 1/4", 1/2" sheet stock)	1	$222.03	$222.03	Re-Used
DC Motor Controllers	3	$66.26	$198.77	Purchased
Misc. Wire	1	$155.04	$155.04	Purchased
Misc. Connectors	1	$155.04	$155.04	Purchased
Networking Equipment (Switch, Fibre Converter, etc.)	1	$103.36	$103.36	Purchased
Vehicle Stability (Foam, Ballast)	1	$77.52	$77.52	Donated
Power Distribution & Circuit Protection	1	$75.82	$75.82	Purchased
Potting Compound (MG 835)	2	$31.59	$63.18	Purchased
Electronics Can Penetrators	1	$53.52	$53.52	Purchased
Pololu Maestro 24	1	$51.63	$51.63	Purchased
Lighting	1	$35.65	$35.65	Donated
Raspberry Pi 2	1	$33.81	$33.81	Purchased
Instrumentation (Current, Voltage, Pressure, Temperature)	1	$29.40	$29.40	Purchased
Payload Motor	1	$15.10	$15.10	Purchased
		ROV Total:	$5,078.79	USD

Topside				
Item	QTY	Price Each	Ext. Price	New/Used
Topside Computer Components	1	$295.69	$295.69	Purchased
Case + Foam	1	$244.33	$244.33	Re-used
Pilot Monitor	1	$155.04	$155.04	Purchased
Co-Pilot Monitor	1	$139.53	$139.53	Re-used
Buttons	18	$6.20	$111.63	Re-used
Networking Equipment (Switch, Fibre Converter, etc.)	1	$103.36	$103.36	Purchased
Power Meters	2	$44.03	$88.06	Re-used
Polycarbonate (0.125" 48" x 48")	1	$49.97	$49.97	Purchased
HDPE (0.5" x 48" x 24")	1	$42.85	$42.85	Purchased
Arduino Mega	1	$39.90	$39.90	Purchased
Rotary Pots + covers	8	$4.65	$37.21	Re-used
USB Panel Mount Plug	4	$8.88	$35.53	Re-Used
Topside Circuit Breaker	1	$24.98	$24.98	Purchased
In-line Circuit Breaker	1	$24.98	$24.98	Re-used
Joystick	1	$19.37	$19.37	Re-used
48 V Power Connectors	3	$5.67	$17.02	Purchased
USB 3.0 Hub	1	$13.14	$13.14	Purchased
Tether Junction Box	1	$9.11	$9.11	Purchased
Ethernet Panel Mount Plug	1	$6.74	$6.74	Purchased
Slider Potentiometers	8	$0.72	$5.77	Purchased
120 V NEMA Power Input Plug (Panel Mount)	1	$0.84	$0.84	Purchased
		Topside Total:	$1,465.07	USD

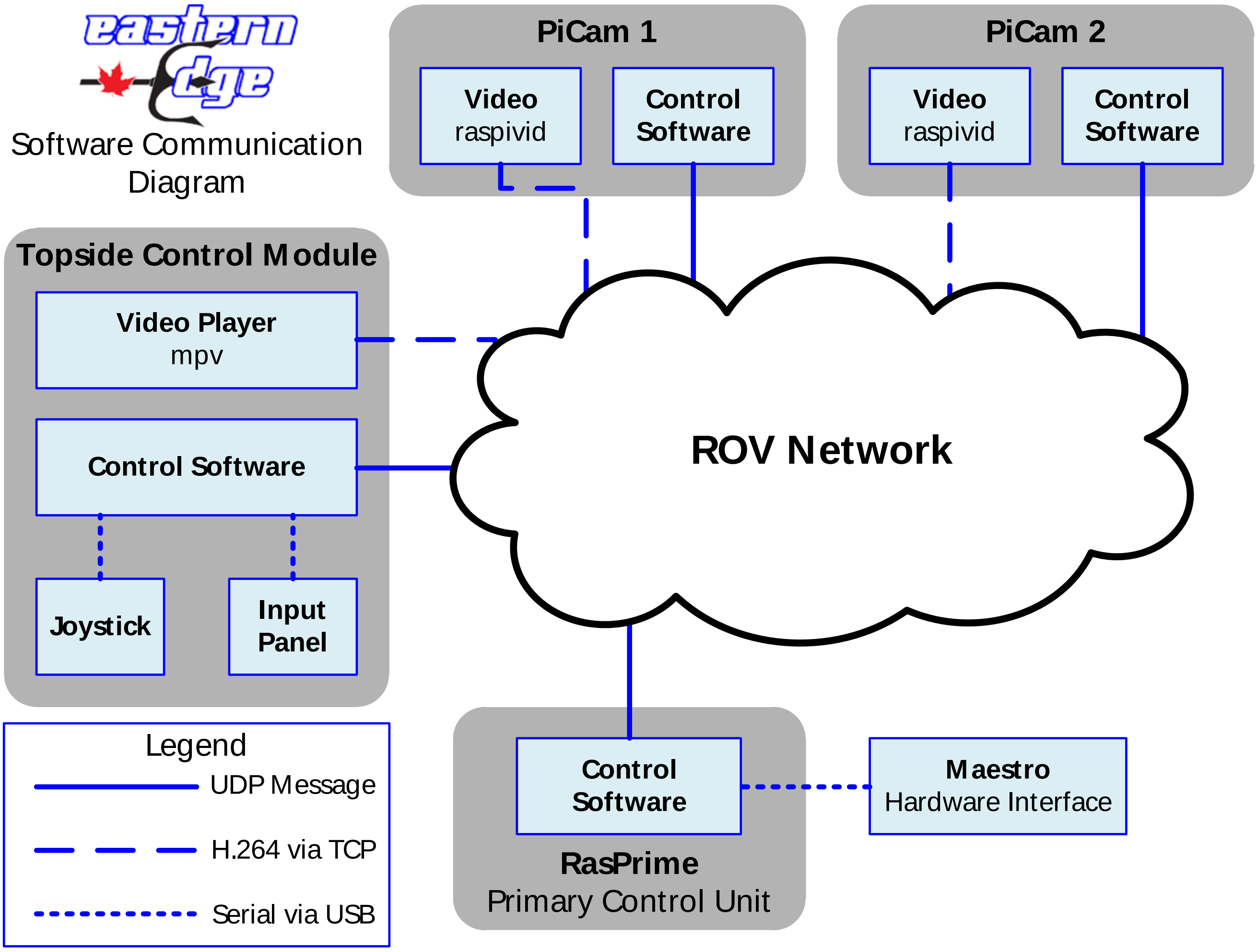
'Blue Puttee' Fair Market Value: $6,543.86 USD

Appendix E – System Integration Diagram (SID)

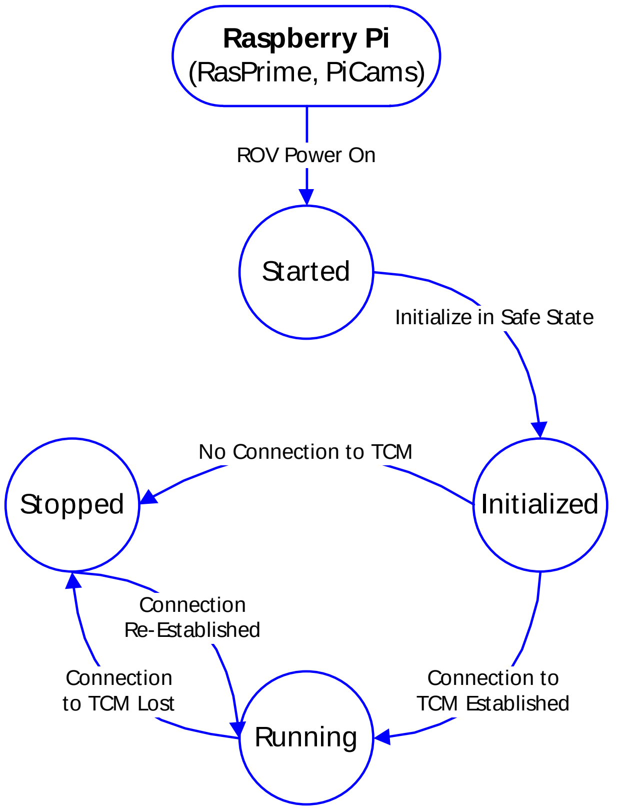


Appendix F – Software Flow Diagrams

Software Communication Diagram



ROV Software Flow Diagram



Topside Software Flow Diagram