Mount Pearl Senior High

Husky Explorer

Technical Report

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Husky Explorer
Mount Pearl Senior High
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FIgure 1: The Husky Explorer team, regional competition, Marine Institute in St. John's, NL, Canada

Abstract

Husky Explorer is a company of 13 students based in Mount Pearl, NL, Canada, which specializes in the design and construction of underwater Remotely Operated Vehicles (ROV).

The Marine Advanced Technology Education (MATE) centre is collaborating with the Eastman company to help in doing "Good for Good". The Husky Explorer team has produced a custom ROV, the Husky ROVER, which meets all requirements for proposal.

This ROV can effectively inspect a hydroelectric dam via a remotely controlled forward-facing camera, replace trash racks and install grout using a pneumatic claw, as well as deploying a secondary ROV to inspect drain pipes. It can remove debris using its manipulator, identify benthic species through a computer vision program and use sensors and collection devices to detect water temperature and pH levels. Finally, the Husky ROVER can detect metal cannon shells using permanent magnets and measure and lift a civil war era cannon with an attached lift bag.

These capabilities are crucial in freshwater areas such as the Boone Lake region. Maintaining the structural integrity of a hydroelectric dam is important not only for safety, but for monitoring the surrounding ecosystem and preserving history, which are extremely important duties to be considered when working within any environment.

Husky Explorer is proud to present the Husky ROVER as its most advanced, intuitive and modular ROV to date. The Husky Explorer team is confident in its ability to provide these professional services to the Eastman company and aims to continue in developing innovative products and solutions for years to come.

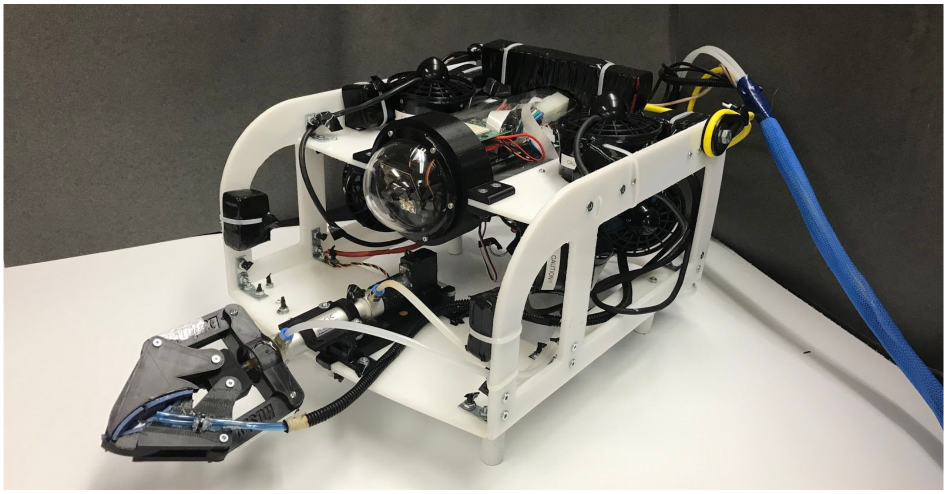

Figure 2: The 2019 Husky ROVER

Design Rationale

The Husky Remotely Operated Vehicle Eastern Region (ROVER) was designed with the Eastman company's requirements in mind. All tools, sensors and actuators were tailored to a freshwater environment. Despite this, the ROV is extremely modular, meaning that it can be re-applied to other uses in the future. The Husky ROVER is 20.5 cm tall, 36.5 cm wide and 41.0 cm long, and has a mass of 12.1 kg.

Mechanical

Propulsion

The ROV is propelled by six Blue Robotics T100 thrusters. Four thrusters are used for horizontal movement and are vectored at 45° to allow for forward and backwards movement, spinning and strafing, while the other two are used for vertical movement. This freedom of movement is extremely important for completing tasks in a timely manner. For example: the ability to strafe is crucial for following the dam's transect line.

Each thruster provides 9.4 N of thrusting force, leading to the following thrust calculations:

$$Vertical\ Thrust : 9.4\ N \cdot 2\ thrusters \cdot \sin 90^\circ\ = 18.8\ N$$

$$Horizontal\ Thrust : 9.4\ N \cdot 4\ thrusters \cdot \sin 45^\circ\ = 32.0\ N$$

Buoyancy

Without additional buoyancy, the Husky ROVER is slightly negatively buoyant. To counteract this downwards force, six blocks of pressure-resistant foam were cut and mounted to the frame to ensure the ROV is neutrally buoyant.

However, when the ROV carries a heavy object in its claw, it lists forwards considerably, limiting the pilot's ability to complete tasks. This is counteracted by two 100ml medical IV bags mounted on each side of the front of the frame. These bags are connected pneumatically via a T-joint to a pump on the surface where they can be inflated or deflated to provide variable buoyancy for the ROV.

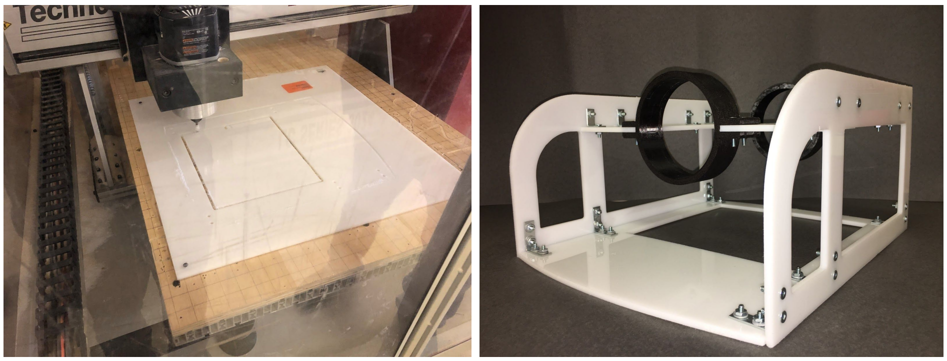

Figure 3: Left - CNC router milling frame components; Right - assembled frame

Frame

The ROV's frame is made of sheets of High-Density Polyethylene (HDPE). These were milled using a CNC router to give precise tolerances.

The frame is held together with a combination of metal and 3D-printed brackets that give it plenty of rigidity and durability. It uses an open design to induce as little drag as possible in the water. Despite this, it still retains many surfaces for the mounting of tools. This allows for the use of custom tools onboard the ROV.

The following table outlines the team's choice to use HDPE over other alternatives. While HDPE is typically weaker than other materials, it is relatively cheap, readily available and lightweight.

	HDPE	**Acrylic**	**Polycarbonate**
Density (g/cm^3)	1.0	1.2	1.2
Impact Strength (J/m)	260	74	440
Tensile Strength (MPa)	24	71	62
Cost	Low	Moderate	Low

Pneumatics

The ROV uses a pneumatic system to power the on-board claw and for filling lift bags. This system is driven at the surface by a compressor filling a small, 150ml reservoir. The air then passes through a manual cutoff valve and a regulator set to 40 PSI before reaching the solenoids. The claw uses a double throw solenoid while the lift bag uses a single throw solenoid. This air then travels through the tether to the ROV through two ¼ in. air tubes and one ⅛ in. air tube. A diagram of this system can be found at Appendix C.

Mission-Specific Tools

Several tools are used on-board the Husky ROVER and all are tailored to the given tasks:

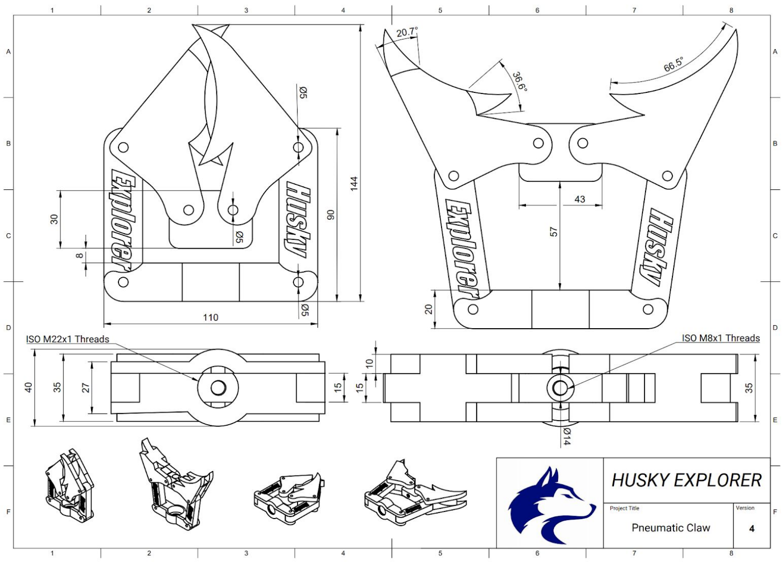

Figure 4: Mechanical drawing of the claw

Primary Manipulator

The ROV's primary manipulator is a pneumatic claw. It is computer controlled and is driven by a pneumatic solenoid valve at the surface. Pneumatic lines run the length of the tether and drive a dual action piston inside the claw that causes it to grip or release. The claw can also rotate 180° to grab objects at different angles.

The claw was first brainstormed by the mechanical team with the tasks in mind, then prototyped with cardboard. From there it was designed in CAD and animated to ensure that it could open and close with a full range of motion. The claw was then 3D printed using PLA by members of the Husky Explorer team. The decision to use PLA over common alternatives is evident in the table below; while PLA, ABS and PETG all possess relatively similar physical properties, PLA is lighter and far easier to print with.

	PLA	ABS	PETG
Density (g/cm^3)	1.3	1.4	1.4
Elastic Modulus (GPa)	3.5	2.6	3.5
Tensile Strength (MPa)	50	70	60
Ease of Printing	Simple	Difficult	Moderate

The claw is very strong as a result of its high-force pneumatic piston. This is a change inspired by the sub-par gripping forces from claws in previous years, which were based on smaller pistons. This year, the piston features a larger cross-sectional area, meaning that the resultant gripping force will be larger. At 40.0 PSI or 275.8 kPa, the piston's force can be calculated as follows:

$$F = plunger\ area \bullet air\ pressure$$

$$F = \pi \bullet (1.25\ cm)^2 \bullet 275.79\ kPa = 135.4\ N$$

Magnets

An array of permanent magnets is attached to the bottom of the ROV's frame. These can be used to detect if a cannon shell is metal or not. Cannon shells are historically made of Iron, which is one of the three ferromagnetic elements, meaning it will interact noticeably with magnets. As the ROV's magnet array approaches a metal cannon shell, the two will attract, thus revealing the identity of the shell to the pilot. The magnets used are small neodymium magnets salvaged from old computer hard drives, due to their high magnetism, low weight and cheap cost.

Sensors

A multitude of digital sensors are used onboard the ROV. They include the humidity, pressure and temperature of the watertight electronics enclosure to detect issues, water temperature to determine the health of the Boone Lake ecosystem, and a gyroscope for the detecting the ROV's pitch and roll. These sensors are useful not only for determining the biological health of a freshwater environment, but also for monitoring the ROV's status and health throughout this process. This gives the ROV pilot and co-pilot real-time information on the ROV throughout the mission.

Figure 5: Modified lift bags used for retrieving the cannon (left) and the degraded tire (right)

Lift Bag

The ROV claw is capable of gripping, manoeuvering and attaching modified lift bags, then filling them with an open-ended pneumatic line. The cannon can be retrieved by hooking the lift bag's carabiner onto the attached U-bolt, thereby allowing the preservation of history on Boone Lake. The degraded rubber tire can be retrieved using an oversized carabiner mechanism, which will aid in preserving the health of the Boone Lake region.

Measurement Device

A 40cm section of ruler attached to a PVC mount allows accurate measurement of cracks in the foundation of a dam, or the dimensions of a civil war era cannon. The ruler is held against the object that requires measuring, and the measurement is read on the ROV's main camera.

Electrical

An electrical SID can be found at Appendix A. The components of the Husky ROVER electrical system are outline below.

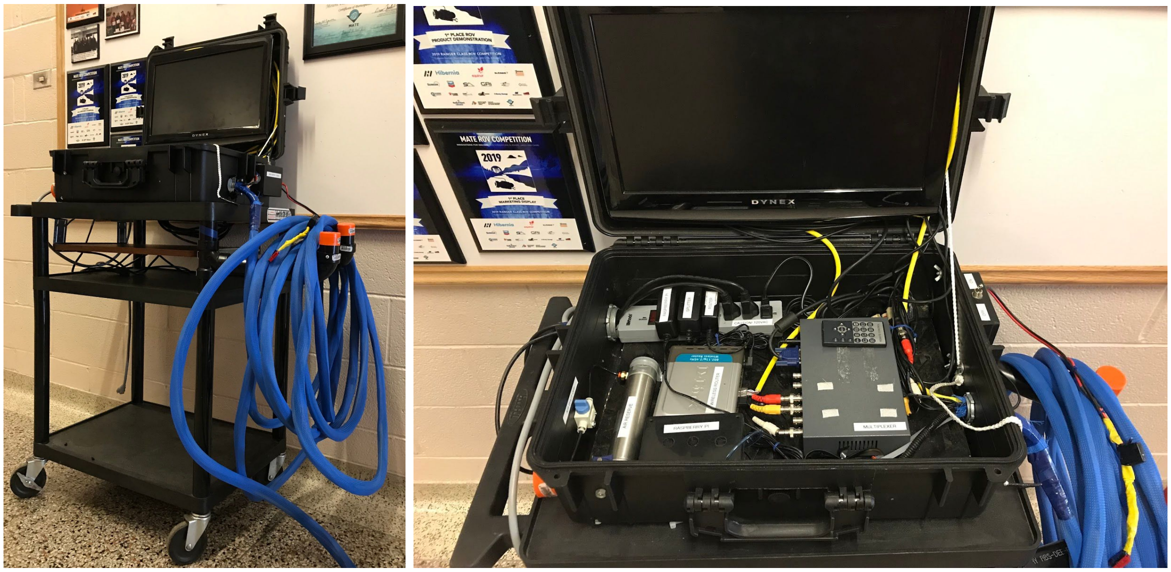

Figure 6: The movable control box

Control Box

The ROV is controlled from the surface by a movable control box mounted to a trolley cart. This box contains an IP switch, a 120 VAC power bar, the majority of the pneumatics system, a Raspberry Pi for controlling the pneumatics system and the main camera multiplexer and monitor. It allows the entire ROV system to be moved anywhere with ease, and also provides a modular area from which to control the ROV.

Tether

The ROV tether consists of two 14-gauge 12 VDC power cables, three analog video cables, a Cat 5e data cable and all 4 pneumatic lines (see pneumatics section). The cables are neatly bundled using blue Flexo PET braided sleeve which can be coiled around the frame of the ROV, making transportation easy. This tether is lighter, less expensive and more flexible than commercial options.

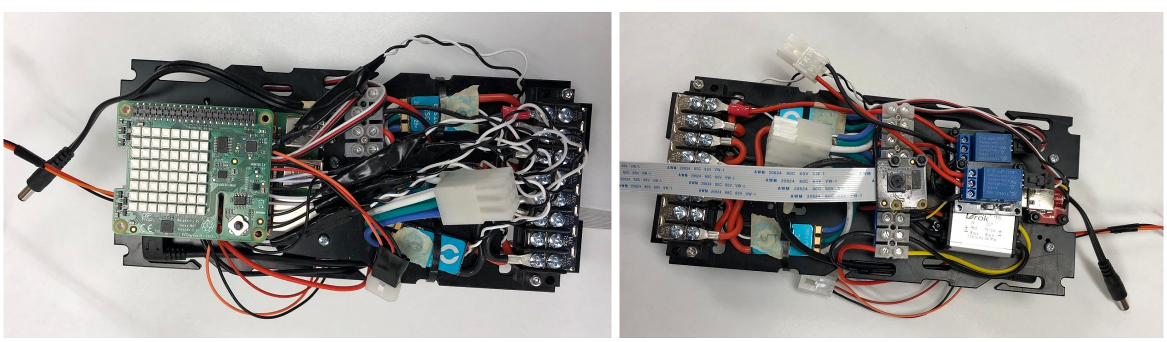

Figure 7: The electronics tray, housed inside the watertight electronics enclosure

Onboard Electronics Enclosure

The watertight electronics enclosure’s contents are all secured to a removable tray to provide organisation and modularity. This allows the ROV to be quickly configured to perform any tasks related to freshwater inspection and repairs.

Notable components in this enclosure are the Onboard Computer, 12VDC and 5VDC distribution blocks, a 12VDC~5VDC step-down buck converter, a Raspberry Pi camera, two single pole relays for the micro-ROV thruster, 6 Electronic Speed Controllers (ESCs) for the thrusters and a sensor board.

Cameras

Four cameras are used onboard of the Husky ROVER, each with its own unique role. A primary analog camera is located in a dome in the front on the vehicle and can tilt up and down using a servo to give the pilot a more complete field of view. A second analog camera is mounted on the micro-ROV and is used to identify areas of muddy water flow inside a drain pipe. A third analog camera is mounted on the side of the ROV for inspecting the dam’s transect line, and a final digital camera is used on the bottom of the ROV for detecting benthic species - this camera is to be used for computer vision software.

Software

The Husky ROVER control system uses four distinct controllers: a computer onboard the ROV, a computer in the control box for operating pneumatics, and two laptops, one for the pilot and one for the co-pilot.

In planning the software design, a large emphasis was placed on object-oriented programming, leading to more organized, readable and modular code. All controllers were programmed in Python 3. While Python is a less efficient alternative to compiled languages such as C, its benefits lie in its popularity, readability and small learning curve for beginners, meaning that more members could learn about the ROV’s software.

A software flow diagram can be found at Appendix D.

Onboard Computer

The onboard computer is a Raspberry Pi Model 3B+. A Raspberry Pi was chosen due to its popularity, availability, high processing speeds and the ability to run Linux and therefore Python. This computer creates a TCP/IP server on boot, to which all other controllers connect. Commands can then be sent to the onboard computer from the pilot or co-pilot, where they will be executed. This computer also reads several sensors and broadcasts their values to a custom-made frontend GUI on the Control Laptops.

Pneumatic Computer

The Pneumatic Computer is a Raspberry Pi located in the surface control box that runs a very simple control scheme. It receives commands from the Onboard Computer to switch on and off the two pneumatic solenoids in the control box, allowing for computer control of the pneumatic claw and lift bag air.

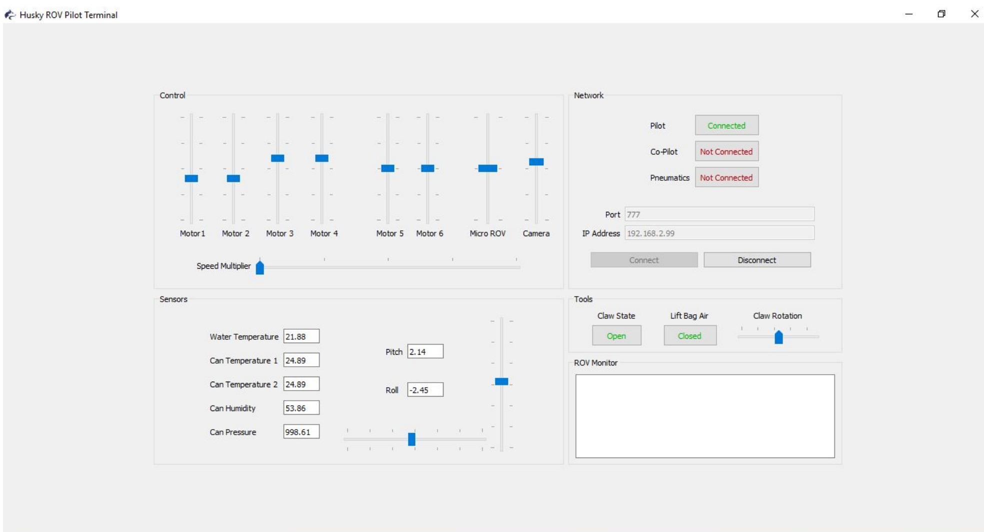

Figure 8: The pilot's laptop GUI

Control Laptops

The ROV is controlled through two Toshiba Portégé R930 laptops. This allows for ROV control via the laptop keyboard. The laptops also run a custom frontend program that displays live telemetry from the ROV including its connection status, sensor values, servo positions and motor speeds. This telemetry is displayed very intuitively for the pilot to see. For example: if the ROV begins to list forwards, a slider on the GUI will change position, alerting the pilot that the ROV is off-balance. The pilot can also control the angle of the main camera from this GUI, allowing for a very large field of view.

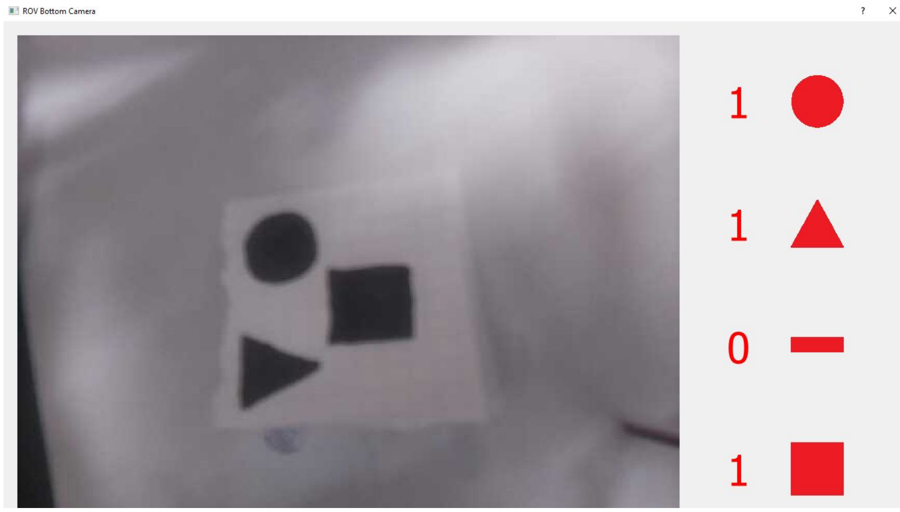

Figure 9: The GUI of the computer vision program

Computer Vision

The ROV also has - through the use of its digital camera - the ability to recognize benthic species using a computer vision program, thereby aiding in the maintenance of healthy waterways. This program uses a shape detection algorithm to detect and record the quantity of each species.

Figure 10: The Husky Explorer micro-ROV for drain pipe inspection

Micro-ROV

The Husky ROVER has the capability to deploy a secondary, smaller ROV to inspect a drain pipe for muddy water flow. The Micro-ROV is a 2 in. ABS tube with a thruster at the rear and a camera/LED combination at the front. This extremely simple design is lightweight, fast and very cost effective.

This design can also easily be carried in the main ROV's claw, allowing it to be quickly and precisely transported to the entrance of the drain pipe.

The Micro-ROV electrical SID can be found at Appendix B.

Build vs. Buy

Building custom parts offers many advantages, including cost-effectiveness and customizability. This can be seen in the design of this year's primary manipulator - a custom-designed, 3D-printed pneumatic claw. This claw was relatively cheap to make, and was tailored to fit this year's mission tasks as it can easily grip ½ in. to 2 in. PVC pipe, as well as U-bolts.

Another custom-fabricated part of our ROV is the frame, which was milled out of sheets of High Density Polyethylene (HDPE) using a CNC router. This process gave the team a great degree of freedom when designing buoyancy, tool and propulsion mounting.

Buying commercial components is also sometimes necessary, as it can offer a fast and often more reliable solution to any problem. For example: almost all electronics onboard are commercial products. This solution was chosen as it is far more time and cost effective when compared to custom PCB design, and is more than enough to meet the needs of the Husky ROVER.

Both lift bags were bought commercially then modified for the 2019 MATE contract. This yields dual advantages: the bags have the reliability of a commercial component while still allowing for the flexibility of a custom-built part.

New vs. Re-Used

In determining which parts would be bought new and which parts would be reused from other years' designs, the team had to carefully consider both cost and ROV performance. The team opted to buy new in areas that were critical to this both year's contract and overall ROV performance, while re-using what we could to reduce both costs and our impact on the environment.

Six T-100 thrusters were purchased from Blue Robotics. These are extremely popular, high-performing and reliable thrusters that the team felt were worth the relatively high cost. Also purchased new was the bulk of the onboard electronics, which was a necessity as this year's electronics system is massively redesigned to both complete the mission tasks more effectively and improve the ROV's overall capabilities. For example: the inclusion of two new relays onboard the ROV allows the pilot to control the micro-ROV's thruster; these may also be reprogrammed in the future to drive another tool, such as an electromagnet.

Re-used components of this year's ROV include the video multiplexer and monitor, pneumatic system and main computers, among other things. These were all high-cost items, where buying new offered no real performance advantages.

Project Management and Teamwork

Scheduling and Planning

The Husky Explorer team prides itself on being extremely well organized. This can be seen in the team's design and manufacturing schedule, which was planned in December of 2018. A graphical representation of this can be seen in Appendix E, the team's Gantt planning chart.

While ambitious, the schedule helped deliver the team to a successful regional competition, with plenty of time to spare for testing and troubleshooting. It also simplified the organizational challenges that occured while the team was simultaneously working on ROV manufacturing, Marketing Display creation and Engineering Presentation preparation.

This schedule was followed closely, and progress was reported at bi-weekly team meetings. These meetings gave all team members the chance to report their department's progress on various tasks, and create action plans for the coming days. In this way, all team members could stay up-to-date on the happenings in other domains, and were always able to work on important tasks. Lead team members also met frequently to discuss high-level planning and discuss the allocation of tasks to other team members.

Organization

The team made use of several collaboration tools to simplify the project's workflow. The most influential of these was Google Drive, which allowed team members to collaborate in real time on any and all documents. This also allowed for live feedback from senior members, which helped guide junior members through difficult tasks. Another technology used was Github, which allowed all members to learn and collaborate on the team's software, in addition to improving the software team's workflow. The team also used group chats to communicate with one another outside of working sessions, made use of a common message board to post team-wide updates.

Problem Solving

As problems arose during all phases of the project, they were dealt with using logical, standard method with which all employees of Husky Explorer are familiar. The process is as follows:

1. Identify the issue and its underlying cause. Eliminate all other possible factors and distill the issue to its simplest form.
2. Evaluate possible fixes and implement the best, depending on cost, time and simplicity.
3. Monitor the solution and ensure that the issue has been resolved completely.

This method has proven to be very effective in treating design, manufacturing, testing and all other types of problems.

Team Composition

At the beginning of the project, team roles had to be assigned. While the Husky Explorer company encourages its employees to gain experience in multiple domains, having each employee work in one primary department lead to a very efficient and organised project.

Senior team members were chosen first, based on previous experience and interest. After that, all other team members were free to select the field in which they would like to work; either Mechanical, Electrical, Software or Business. These roles were assigned primarily based on interest, as employees will produce the best results in positions about which they are passionate, where they are driven to learn and do well.

Figure 11: Ian, Mackenzie and Truman working safely in the Husky Explorer workshop

Safety

Safety Philosophy

At Husky Explorer, all employees are taught that safety is paramount. It is the philosophy of Husky Explorer and all of its members that safety comes before anything else. This means that the company is willing to spend more time, money and resources on a solution if it is seen to be safer than another.

Every team member has been trained in the use of every tool in the workshop through quizzes administered by the team. Only an employee who has received a perfect score on a quiz can operate the corresponding tool. In addition to this, firm In-Workshop and On-Deck safe operating procedures have been established, and can be found in Appendix F.

Safety Features

The ROV complies with every safety direction given by MATE, many of which can be seen in the below table.

Feature	Description
Rounded edges	All sharp edges of the ROV were filed, removed or covered such that no harm can occur while handling the ROV.
Strain relief on both ends of the tether	The tether is secured at the surface through a clamp and on the ROV through rotating tie-downs to ensure absolutely no strain on wires or connections.
Shrouded thrusters	All thrusters on the ROV and Micro-ROV are shrouded to IP20 standards to prevent harm from rotating components.
Power supply fuse	There is a 25 A fuse placed 15 cm from the positive terminal of the power supply.
Caution labeling	All hazardous components of the ROV are labeled as such. These components include thrusters, rotating components, 12VDC and 120VAC power (separately) and pneumatic parts.
Waterproofed electronics	All electrical components on the ROV are either housed in the watertight electronics enclosure or have been waterproofed using marine epoxy and silicone.
Component ratings	No components are used outside their rated specifications. For example, all pneumatics are rated to above 100 PSI even though the system is regulated to 40 PSI.
Power cut off switches	A single pole single throw switch is located on the positive wire of the 12VDC supply, and the 120VAC power bar also has an easily accessible cutoff switch.
Electronics enclosure sensors	Temperature, pressure and humidity sensors are located inside the electronics enclosure and their data is displayed at the surface. This allows the team to detect dangerous situations, such as a breach in the enclosure.

Accounting

Budget

At the beginning of the project, all team members met to discuss and formulate a tentative budget. Once finalized, all team members adhered to the budget during the ROV's build phase. To ensure reasonable spending, all purchases had to be cleared by the company's CFO or another senior member. In addition to this, all parts were sourced from multiple vendors before purchasing to ensure that all prices were fair.

Travel estimates were based on flight data at the time as well as average accomodation pricing for thirteen students plus two mentors in Kingsport. A full budget along with travel estimates can be found at Appendix G.

Project Costing

A detailed breakdown of the ROV's cost can be found at Appendix H. The team adhered to the budget very well, and no funds were wasted or misallocated.

Critical Analysis

Testing and Troubleshooting

It was critical to the ROV's safety and performance that adequate testing be performed before any full-scale run. These tests are described in the table below:

Test	Description
Waterproofing Test	All components of the ROV were tested to be waterproof over an extended period of time both separately and together in varying depths of water, from 1 to 5 meters.
Power-On and Power-Off Tests	This test ensures that all controllers boot upon power-up, that all sensors read nominal values, and that all components of the ROV are powered on. Upon power-off, all components should return to a safe state, and should be OK to power-on once again.
Off-Nominal Connection Test	This test involves irregular connections from the pilot's control system to the ROV, and tests worst-case scenarios such as a mid-run disconnection. This ensures that if the connection were to be lost, the ROV will remain in a safe state until it is able to re-connect.
	This involves setting all thrusters to maximum sensitivity and powering

Max Current Draw Test	all six simultaneously for an extended period of time, to create a large current draw. This test ensures that all electrical components can handle that amount of current, and that other components in the system continue to receive enough power.

If any of these tests were to produce unfavorable results, then troubleshooting would occur to find the source of the issue. Team members would follow the problem solving steps found in the *Problem Solving* section, under *Project Management*. This clearly defined protocol provided a standardized way for all team members to troubleshoot issues quickly and effectively.

Of course, troubleshooting can be avoided by preventing issues with careful planning. The team prototyped almost all systems for this year's ROV before they were implemented at full scale. This allowed employees to work through potential issues before they became too difficult to fix, and made actual implementations of ideas far easier to create.

For example: all onboard circuits were first tested on a breadboard before being made more permanent inside the enclosure. Another example is a cardboard mockup of the frame that was created before the frame's material was milled. This allowed for the testing of mounting locations and camera angles without any risk.

Challenges and Problem Solving

Technical

A large challenge for the team this year was the onboard watertight electronics enclosure. Cables enter this enclosure at the rear via cable penetrators. They are first inserted into these penetrators, and are then potted - or sealed - through the use of a marine epoxy. Unfortunately, through a misunderstanding, epoxy was not allowed sufficient time to dry before it was tested underwater, and water entered the enclosure.

This was obviously a mission-critical component, and on such a short time frame, the team, who were unaware of the nature of the problem, urgently tried all fixes. The dome on the front of the enclosure was tested, O-rings were replaced, even the enclosure itself was inspected. After ruling out all other possible causes, the penetrators were determined to be the issue.

The team quickly re-applied epoxy, waited the appropriate amount of time, then re-tested the enclosure. Thanks to the careful troubleshooting and team communication, the team was able to carry on with the rest of the ROV's assembly.

Interpersonal

At 13 members, Husky Explorer's 2019 team is its largest to date. This posed a problem for the team as it was difficult at first to find meaningful roles for all members. However, with the guidance of returning members, all employees of the company were able to find roles that suited their interests. This afforded every member of the team the opportunity to learn about a domain in business or engineering that interested them, while still allowing the team to develop a high-performance ROV.

Lessons Learned

Technical

This year's onboard electronics are mounted on a removable, modular tray inside the watertight enclosure. This tray is easily removable to allow employees to work on the electronics quickly and efficiently. This design worked very well and saved a lot of time.

This modularity can be applied to other areas of the project as well. For example: the pneumatic claw on the front of the ROV is effectively permanent. To remove it for any reason would require a great deal of effort. If this design were to be made modular, as was the electronics system, then it could be fixed or upgraded more easily.

Interpersonal

As the progressed, and the Husky Explorer team dynamic became more concrete, a flat leadership model became clear. This means that while the team's more senior members were still able to provide direction and assistance to those that needed it, all team members held equal say in company decisions, and were free to be autonomous in their work.

The team found that this not only cut down on unnecessary interpersonal conflict, but also allowed all team members to feel more dedicated and invested in the project while still tailoring their commitment level to their personal schedule. This model will continue to be used in future years.

Skills

Before the details of the MATE contract were released, the team prepared for the design phase by completing training modules, assisted by senior members. These modules included basic circuits, where all team members learned to solder and use multimeters; basic programming where team members learned to code using Arduino; and basic CAD, where team members modeled and 3D printed objects using Solidworks.

These modules gave junior members a chance to learn valuable skills while also giving senior members experience in teaching and mentoring.

Future Improvements

This year's control system is based on Transmission Control Protocol over Internet Protocol or TCP/IP. While the control system is very effective, a more appropriate choice would have been User Datagram Protocol, or UDP.

TCP relies on a continuous connection between devices on the network. This means that if a device is disconnected, it must reconnect before it can once again communicate. While this is advantageous in some scenarios due to its reliability, in this case it made for more complicated, less efficient code, and created higher latency due to its larger overhead. Ideally, future ROVs from Husky Explorer will use UDP, resulting in superior software.

Another improvement that can be made is in team recruiting. This year's company was very heavily weighted towards engineers, meaning that there were very few members who specialized in accounting, marketing and finance. This proved to be problematic as a large portion of the MATE contract involves accounting, sponsorship, budgeting and other financial tasks. In the future, the Husky Explorer team will recruit more business-oriented students, who can also gain valuable experience through the MATE program.

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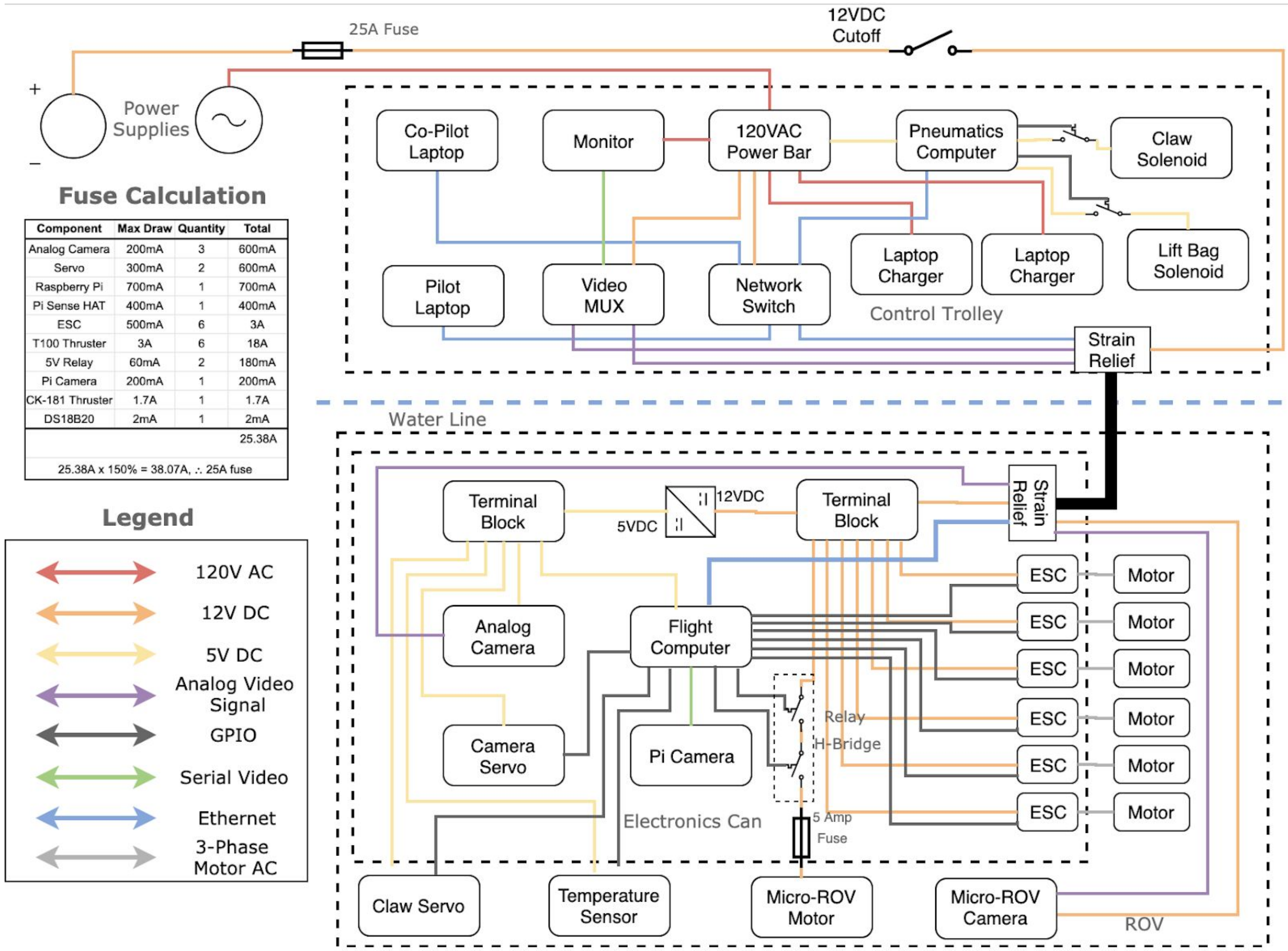
- Mount Pearl Senior High

Without their continued support, we would not have been able to pursue our development in the field of underwater robotics. We would also like to thank our teacher mentors - Mr. Paul King and Mr. Craig Janes - for allowing us to use their workspace.

Finally, we are grateful for the MATE organization - the annual ROV competition has given Husky Explorer incredibly valuable experience in the fields of engineering, science, technology and business. For this opportunity, we are extremely grateful.

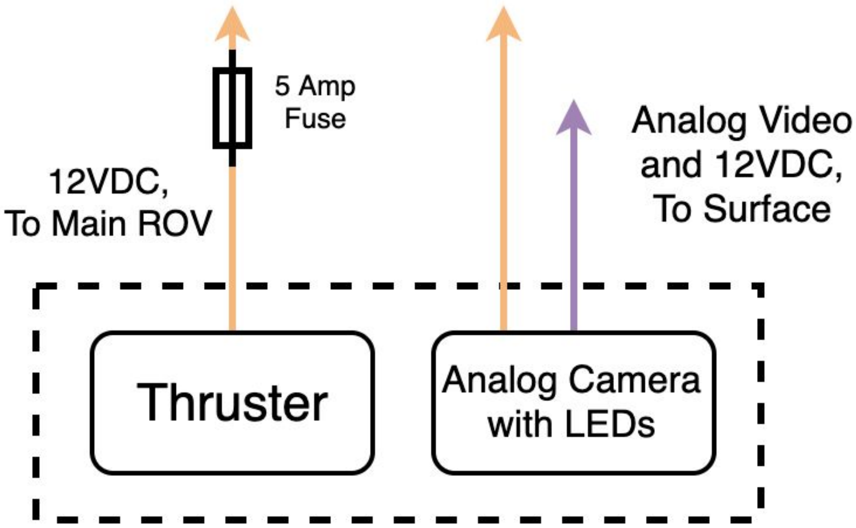
Appendices

Appendix A: Main Electrical SID and Fuse Calculations

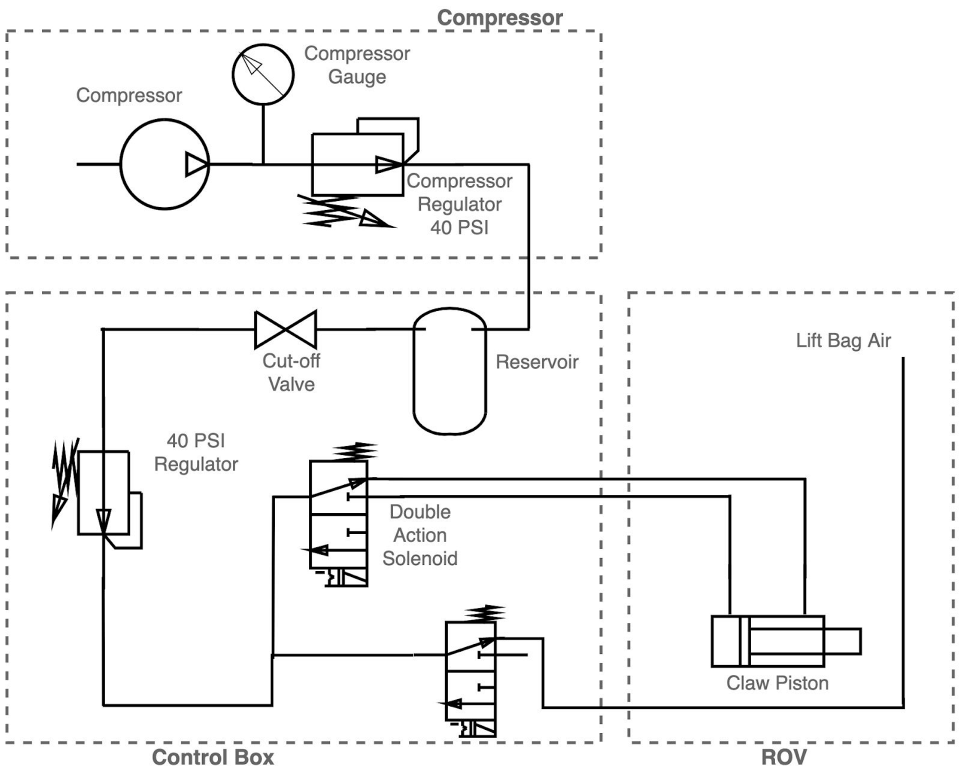


Component	Max Draw	Quantity	Total
Analog Camera	200mA	3	600mA
Servo	300mA	2	600mA
Raspberry Pi	700mA	1	700mA
Pi Sense HAT	400mA	1	400mA
ESC	500mA	6	3A
T100 Thruster	3A	6	18A
5V Relay	60mA	2	180mA
Pi Camera	200mA	1	200mA
CK-181 Thruster	1.7A	1	1.7A
DS18B20	2mA	1	2mA
			25.38A
25.38A x 150% = 38.07A, ∴ 25A fuse			

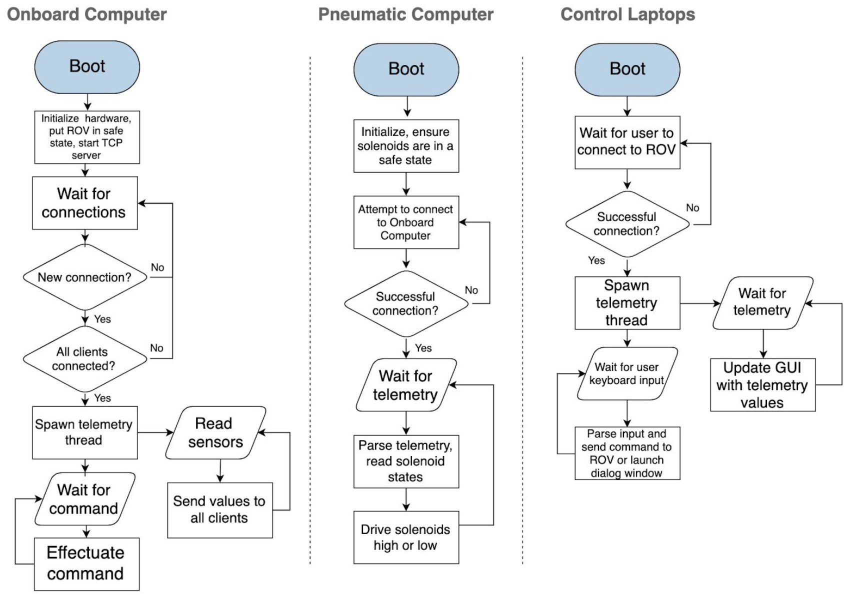
Appendix B: Micro-ROV SID



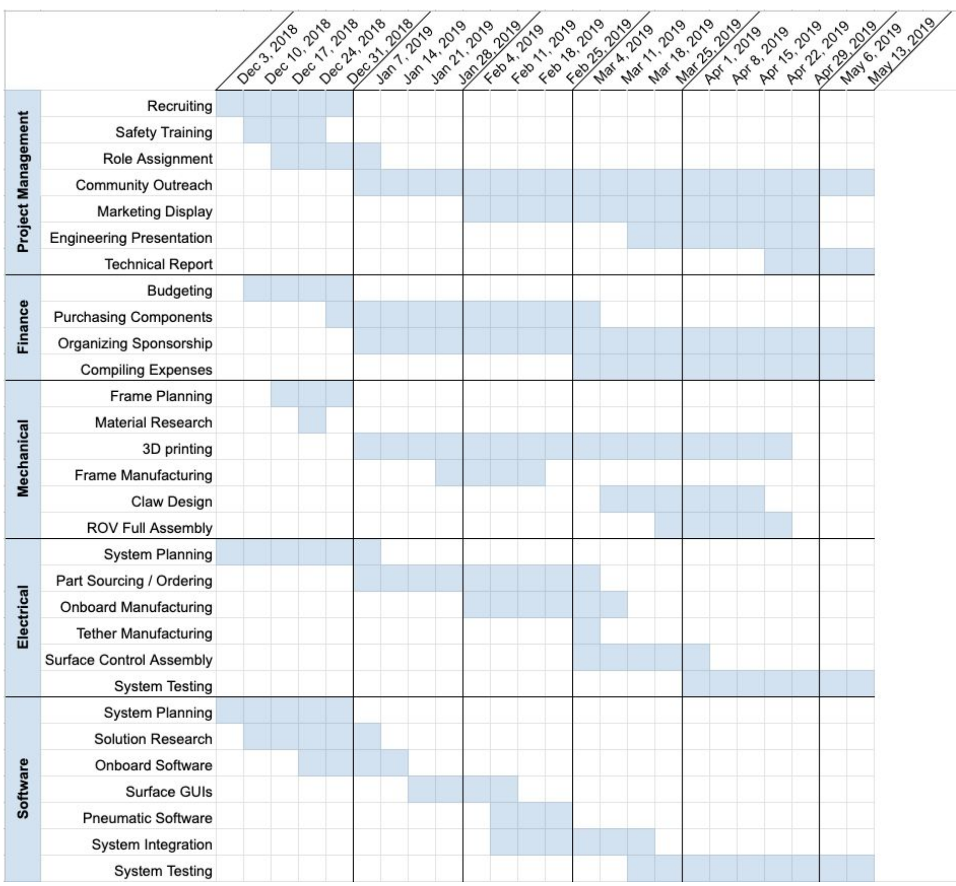
Appendix C: Pneumatic SID



Appendix D: Software Flowchart



Appendix E: Gantt Chart



Appendix F: Safe Operating Procedures

In-Workshop	On-Deck
General Checklist ● Ensure workspace is clear, no tripping hazards ● PPE is worn when appropriate ● Check all equipment before use ● All employees in the workshop are safety trained Soldering ● Wear safety glasses and a face mask ● Ensure no wires are live ● Ensure a clean workspace ● Inform others that you are soldering Using Power Tools ● Wear safety glasses, gloves and masks when appropriate ● Ensure the workspace is clean ● Inform others that you are using those tools	Setup, Boot and Launch ● Ensure the area is clear and all team members are ready ● Attach the ROV's power supply, connect the compressor and control box to 120VAC power ● Connect the compressor to the pneumatic system ● Alert all team members and power on the ROV ● Connect to the ROV and ensure all sensor values are nominal ● Test thrusters, servos and pneumatics ● Place the ROV in the water and ensure all air is removed ● Deploy the ROV ROV Retrieval ● Pilot alerts deck crew that the ROV is surfacing ● Deck crew informs pilot that the ROV has surfaced ● Pilot removes hands from controls ● Deck crew retrieves the ROV ROV Maintenance ● Verify all electronics are in working order, all sensors are reading correctly ● Check for scratches, holes or other damage ● Check thruster guards, strain relief and other safety components ● Grease the O-Rings, clean the electronics enclosure and flush the pneumatic lines

Appendix G: Project Budget

School: Mount Pearl Senior High		**Organisation:** Husky Explorer		
Mentor(s): Mr. Paul King		**Period:** Dec 1, 2018 to Jul 1, 2019		
Income				
Sources				**Amount**
Mount Pearl Senior High				$1,000.00
Memorial University of Newfoundland				$945.00
Marine Institute (contingent upon advancing to the international competition)				$20,000.00
Expenses				
Category	**Description**	**Type**	**Projected Cost**	**Bugeted Value**
Mechanical	Frame materials and hardware	Purchased	$500.00	$500.00
	Electronics enclosure and penetratc	Purchased	$300.00	$300.00
	PLA Filament	Re-Used	$50.00	---
	Pneumatics system	Re-Used	$300.00	---
Electronics	Trusters and ESCs	Purchased	$1,200.00	$1,200.00
	Sensors	Purchased	$50.00	$50.00
	Control Laptops and Raspberry Pis	Re-Used	$2,000.00	---
	Wire, solder and other materials	Re-Used	$200.00	---
	Surface side control system	Re-Used	$700.00	---
	Tether cables and lines	Re-Used	$300.00	---
	Micro-ROV thruster and camera	Re-used	$200.00	---
Travel	Airfare from St. John's to Kingsport	Purchased	$15,000.00	$15,000.00
	Accomodations	Purchased	$5,000.00	$5,000.00
	Transportation	Purchased	$5,000.00	$5,000.00
	Food and Drink	Purchased	$2,000.00	$2,000.00
General	Marketing Poster	Purchased	$200.00	$200.00
			Total Income	$21,945.00
			Total Expenses	$33,000.00
			Total Re-Used	$3,450.00
			Fundrasing Needed	$7,305.00

Note: all values are in Canadian Dollars (CAD)

Appendix H: Project Costing

	School: Mount Pearl Senior High		**Organisation:** Husky Explorer		
	Mentor(s): Mr. Paul King		**Period**: Dec 1, 2018 to Jul 1, 2019		
	Item	**Units**	**Cost**	**Source**	**Total**
Mechanical					
Enclosure	O-Ring Set	1	$1.80	Purchased	$1.80
Enclosure	O-Ring Set (4")	1	$3.55	Purchased	$3.55
Enclosure	Cable Penetrator	14	$3.55	Purchased	$49.70
Enclosure	Aluminum 14 Hole Cap	1	$33.16	Purchased	$33.16
Enclosure	O-Ring Flange (4")	2	$34.34	Purchased	$68.68
Frame	HDPE Sheet 12 in. x 24 in.	4	$19.12	Purchased	$76.48
Frame	Mounting Bracket	6	$5.92	Purchased	$35.52
Frame	Dome End Cap (4")	1	$39.00	Purchased	$39.00
Pneumatics	Brass Coupling (1/8")	1	$1.79	Purchased	$1.79
Pneumatics	Coupling (1/8")	1	$1.75	Purchased	$1.75
Pneumatics	Brass Reducer (1/4"x1/8")	2	$2.00	Purchased	$4.00
Pneumatics	Air Compressor	1	$169.29	Re-Used	-
Pneumatics	Vex Pnumatics Kit	1	$298.99	Re-Used	-
Hardware	Pan Head	1	$8.89	Purchased	$8.89
Hardware	Nut/Hex	1	$5.61	Purchased	$5.61
Hardware	Washer/Flat	1	$3.98	Purchased	$3.98
Hardware	U-Bolt/132	2	$1.82	Purchased	$3.64
Hardware	Springsnap/2-1/4"	2	$2.79	Purchased	$5.58
Hardware	Eye Bolt/1/4*3	2	$0.99	Purchased	$1.98
Hardware	Bolt/1/2"	1	$2.79	Purchased	$2.79
Hardware	90° Angled Bracket (1")	9	$0.89	Purchased	$8.01
Hardware	250Pcs Standoff Spacer	1	$17.69	Purchased	$17.69
Hardware	Pelican Control Box	1	$49.99	Purchased	$49.99
Hardware	PLA Filiment	2	$25.99	Purchased	$51.98
Electrical					
Onboard Electronics	15 Pin Ribbon Cable	1	$12.99	Purchased	$12.99
Onboard Electronics	Electronics Tray	1	$93.42	Purchased	$93.42
Onboard Electronics	Blue Robotics T100	6	$170.60	Purchased	$1,023.60
Onboard Electronics	Blue Robotics Basic ESC	6	$35.00	Purchased	$210.00
Onboard Electronics	2x20 Female Pin Header	1	$9.99	Purchased	$9.99
Onboard Electronics	Raspberry Pi 3 B	2	$69.99	Re-Used	-
Onboard Electronics	12V to 5V Buck Converter	1	$10.88	Purchased	$10.88
Onboard Electronics	Water Proof Connectors	1	$15.19	Purchased	$15.19
Onboard Electronics	Raspberry Pi Sense HAT	1	$14.99	Purchased	$14.99
Onboard Electronics	5V USB A Breakout Board	1	$4.67	Purchased	$4.67
Onboard Electronics	1 Channel 5V Relay	2	$8.99	Purchased	$17.98
Onboard Electronics	Analog Waterproof Camera	1	$189.99	Re-Used	-
Onboard Electronics	2.1 mm Board Camera	1	$16.50	Purchased	$16.50
Surface Control	DLink Router	1	$39.99	Re-Used	-
Surface Control	Video Multiplexer	1	$249.98	Re-Used	-
Surface Control	Cat 5E Cable	3	$7.99	Re-Used	-
Surface Control	50ft. 14 Gauge Wire	1	$25.99	Purchased	$25.99
Surface Control	Cat 5E Tether	1	$59.97	Purchased	$59.97
Surface Control	Monitor	1	$299.99	Re-Used	-
Surface Control	4 Channel Relay Module	1	$10.19	Purchased	$10.19
Surface Control	5 port power bar	1	$14.99	Re-Used	-
Surface Control	Toshiba Portege R930	2	$899.99	Re-Used	-
General					
General	Total Shipping Fees.	1	$238.49	Purchased	$238.49
General	Team Registration.	1	$155.00	Purchased	$155.00
General	Team Presentation Pamphlets.	7	$20.00	Purchased	$140.00
General	Team Marketing Poster.	1	$182.85	Purchased	$182.85
Travel	Airfare	1	$15,000.00	Purchased	$15,000.00
Travel	Accomodations	1	$5,000.00	Purchased	$5,000.00
Travel	Food and Drink	1	$4,000.00	Purchased	$4,000.00
Travel	Transportation and Shipping	1	$4,000.00	Purchased	$4,000.00
Income					
Donations	Memorial University	1	$945.00	Cash Donated	$945.00
Donations	Mount Pearl Senior High	1	$1,871.93	Cash Donated	$1,871.93
Donations	NL MATE Regional	1	$20,000.00	Cash Donated	$20,000.00
Donations	Midgard Gaming	1	$500.00	Cash Donated	$500.00
Donations	Redwood Construction	1	$100.00	Cash Donated	$100.00
Donations	Wood	1	$500.00	Cash Donated	$500.00
Donations	Stantec	1	$500.00	Cash Donated	$500.00
Donations	Academy Canada	1	$200.00	Cash Donated	$200.00
Donations	Roebothan McKay Marshall	1	$200.00	Cash Donated	$200.00
Donations	Fortis	1	$1,000.00	Cash Donated	$1,000.00
Donations	Tim O'Connor	1	$50.00	Cash Donated	$50.00
Donations	Modern Paving	1	$100.00	Cash Donated	$100.00
Donations	Logan Drilling	1	$500.00	Cash Donated	$500.00
Donations	Ready Kilowatt Credit Union	1	$100.00	cash Donated	$100.00
Totals					
	Total ROV Cost				$2,001.93
	Total Expenditure				$26,718.27
	Total amount fundraised (as of May 20th, 2019)				$26,566.93
	Total amount left to fundraise				$151.34

Note: all values are in Canadian Dollars (CAD)