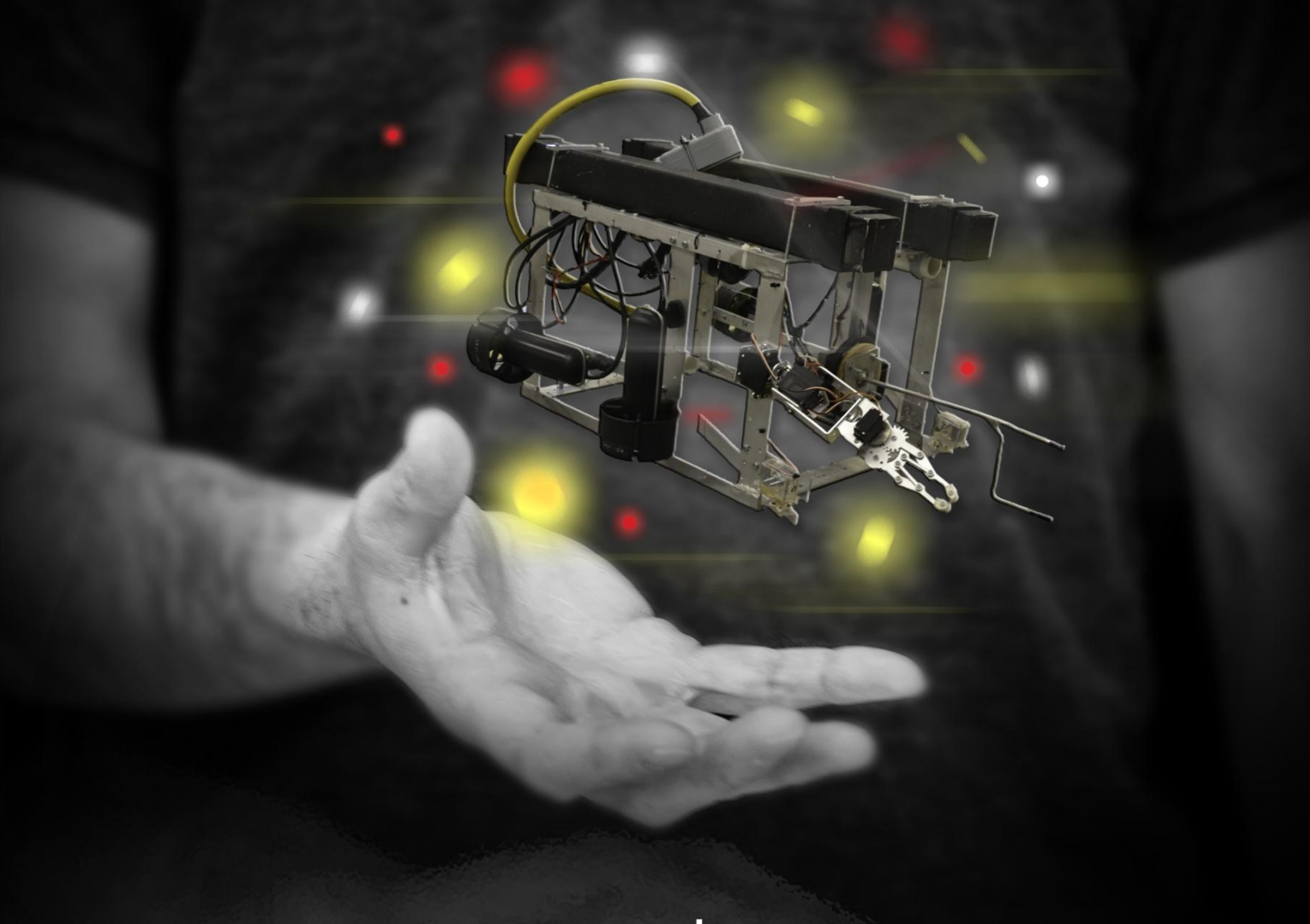
MATE 2014 International ROV Competiton

Clarenville High - Cougar Robotics Inc.

TECHNOLOGY
REPORT



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Mate International Technology Report - 2014

Cougar Robotics Incorporated

Clarenville High School, Clarenville, NL, Canada
http://www.chs.k12.nf.ca/ROV.htm

Abstract

In the rough, unforgiving waters of the Great Lakes, the wreckage of over 50 ships has been discovered. It is in shipwrecks such as these that Remotely Operated Vehicles (ROV) play an integral role in the discovery and subsequent analysis of these wreckages. Over this past year, Cougar Robotics Inc. has worked diligently to construct the most innovative and optimal ROV for the purpose of underwater exploration and preservation. The culmination of our efforts has led to our proud presentation of ROV *Argo*. Our ROV is honorably named after the iron-screw steamer *Argo*, which sank off the coast of our home province of Newfoundland, Canada in 1859. The ROV *Argo* was strategically designed and constructed with drag, cost, and environmental concerns at the forefront, resulting in an end product which is the most cost-efficient, speed-efficient, and environmentally friendly ROV, capable of completing the key tasks of its mission. The success of ROV *Argo* is a clear indicator of the improvements that have been made in ROV technology with regard to accessible and affordable underwater exploration. ROVs, such as *Argo*, open up a world of possibility to explore our past now in the present and into our future.

Cougar Robotics Incorporated of Clarenville, Newfoundland and Labrador, Canada is proud to present the following technical report, complete with the details of ROV *Argo*. Within this report we have outlined the decision-making process, the key design features used during the building process, and the obstacles we had to overcome to bring it to fruition.

Nomenclature

v = The speed of ROV [m/s]

F_d = Drag Force on ROV [N]

P = Pressure [Pa]

τ = Shear Stress Coplanar with Cross Section [Pa]

A = Reference Area [m^2]

C_d = Drag Coefficient

P = Mass Density of Fluid [kg/m^3]

R = Resistance [Ω]

T = Temperature [^oC]

F_g = Force of Gravity [N]

F_b = Force of Buoyancy [N]

W = Vehicle Weight [N]

m = Mass of Vehicle [Kg]

BHN = Brunel Hardness Number [HB]

TS = Tensile Strength [MPa]

σ = Yield Strength [MPa]

I = Current [A]

V = Voltage [V]

t = Time [sec]

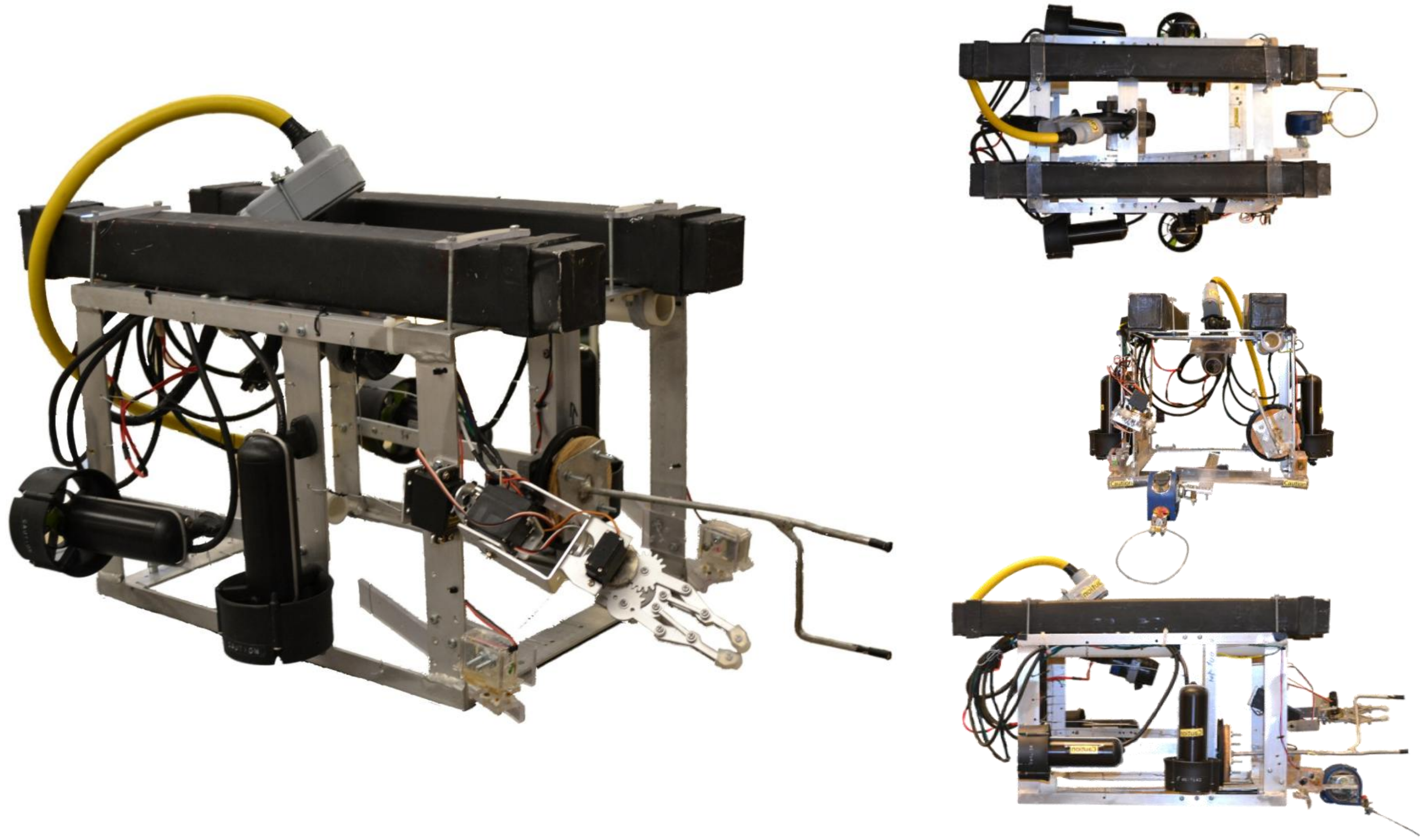


Figure 1: ROV *Argo* - Isometric and Orthographic.. (A. Short, 2014)
Argo is a Class 3, remotely operated vehicle (ROV) designed and constructed by Cougar Robotics Inc. 2014.

Introduction

Early in the fall of 2013 Cougar Robotics Inc. began to tirelessly prepare and brainstorm for a demanding year centered on the exploration and preservation of underwater shipwrecks. Utilizing the strengths of our company members to the utmost and taking inspiration from working ROVs in Shipwreck Alley, Cougar Robotics Inc. was able to create ROV *Argo* - a lightweight, efficient, and compact ROV capable of completing all mission tasks. Featuring highly efficient and powerful thrusters, a unique frame design, original hand-crafted end-effectors and a one of a kind, custom-programmed robotic gripper, ROV *Argo* offers endless possibilities in its utilization. From its plug and play systems to its numerous sensor options, *Argo* can be adapted to satisfy the needs of its clients. Through dedication, teamwork, and innovation ROV *Argo* has been designed to overcome the many challenges presented to it. Furthermore, Cougar Robotics Inc. is proud to submit this year's technology report to explain our company's outstanding, year-long project. We hope you enjoy learning about ROV *Argo* as much as we have enjoyed creating it.

Design Rationale

Cougar Robotics Incorporated made every attempt to build the ROV from our very own hand-crafted components. Nearly all tools, sensors, control systems, frame, and buoyancy, were constructed by our company. Many components were constructed from conventional and household products to decrease cost. Supplies and materials such as plastic containers, ABS pipe, automobile parts, and tubing are some examples of simple objects that were utilized in the overall design. Nonetheless, ROV *Argo* was entirely designed to focus on accomplishing the mission tasks as efficiently as possible. *Argo* has been completely built from the ground up, with every component, part, and system, having undergone an entire redevelopment. The company has developed and implemented an entirely new control system, propulsion, buoyancy, camera, frame, and tether. The function of the ROV has been optimized through the design and modifications which were made throughout the testing process. We strategically chose all systems, end effectors, and tools to maximize the efficiency and maneuverability of ROV *Argo*.

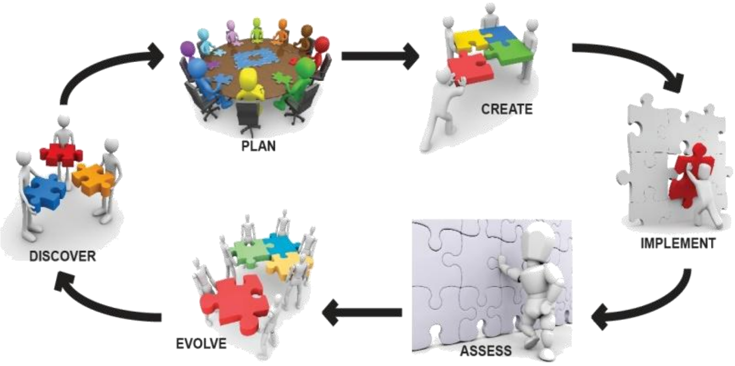


Figure 2: Six Step Design Process. (Richaven PLLC, 2014)
The design process is often circular, looping back on itself as the team learns more about the project.

The development and construction of ROV *Argo* was based on a strategic and technically designed plan. Throughout the project the company followed a six step design process (Figure 2). Beginning at the 'Discover' stage, the team analyzed and hypothesized, learning and discovering unknown things about the anticipated project. Next, we would 'Plan', trying out certain ideas or proposals that may lead to better understanding. The 'Create' stage required understanding and iteration of the concepts proposed to demonstrate our understanding of the project. During the 'Implement' stage, the team brought together and document all of the ideas that were the results of the iterative process. Next, we would 'Assess', measuring and combining analysis of the project with testing of the results. Finally, during the 'Evolve' stage we learned from assessment of the results and, through employing all of the steps of the design process, we delivered a final product.

Prior to production, components were analyzed and tested using various design software such as SolidWorks, COSMOS FloWorks, and Under Pressure. Prototypes were constructed, tested, and redesigned until an optimal solution was obtained. A final fluid flow analysis was conducted to reduce drag and optimize performance. The entire process promoted minimal wastage and increased productivity, allowing our company to produce a highly effective and successful product.

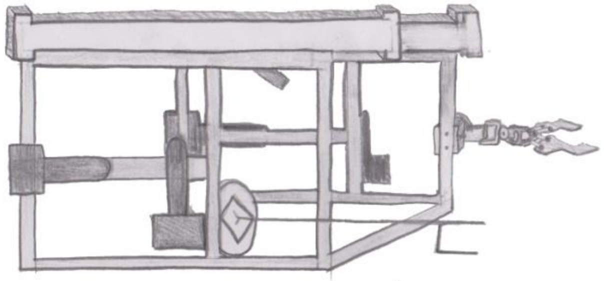


Figure 3: Sample Sketch - Rov *Argo*. (B. Snow, 2014)
Sketching is an important component of the 'Plan' stage.

Frame

When constructing a building, one starts "from the ground up." In the ROV construction world, this would be the frame. Three options were considered for the frame's material and design. The first option was a square frame constructed from 0.031m ID (1.25 inch) polyvinyl chloride (PVC) pipe and fittings. The second option was a similar design made from 0.002m x 0.025m aluminum flat bar. The third option was a U-shaped frame fabricated from 0.0047m thick polycarbonate resin thermoplastic.

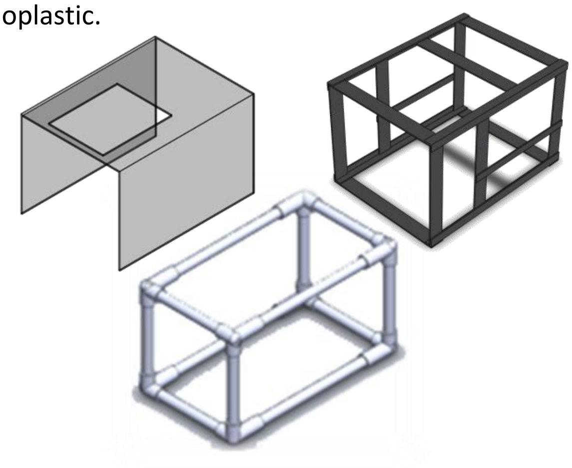


Figure 4: Choice of Frames. (C. Sawler, 2014)
Possible frame designs were constructed in SolidWorks and fully tested prior to production.

The choice of frame design is dependent on its susceptibility to tool placement, but, most importantly, its resistance to drag and reduced water flow. All frames were drafted in SolidWorks and underwent a fluid flow analysis using COSMOS FloWorks. The data is recorded on the next page.

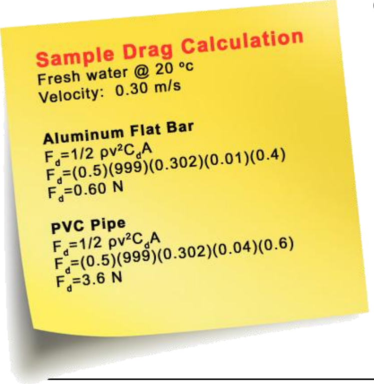
COSMOS FloWorks Flow Analysis Data			
Frame	**Drag (F_d)**	**Pressure (P)**	**Shear Stress (τ)**
0.0047m Polycarbonate Resin Thermoplastic	-0.29845 N	101598 Pa	6.4249 Pa
0.031m ID (1.25 inch) Polyvinyl Chloride (PVC) Pipe	-0.84657 N	345727 Pa	16.6572 Pa
0.002m x 0.025m Aluminum Flat Bar	-0.18465 N	65598 Pa	4.2180 Pa

Figure 5: COSMOS Fluid Flow Analysis. (P. Dove, 2013)
A fluid flow analysis of three frame possibilities, indicating the simulated drag experienced @ v =0.30 m/s. T= 20 °C.

COSMOS FloWorks allowed us to simulate complex 3D fluid flow analysis providing insight into how a fluid will flow through the frame without ever having to build it. From the data we were able to determine which model exhibited less drag and exactly where fluid flow would be obstructed. From the simulated tests it was apparent that the aluminum flat bar experienced a horizontal translation drag of nearly half of the polycarbonate resin thermoplastic and a quarter of the PVC.

Figure 6: FloWorks Simulation - Front View. (C. Sawler, 2014)
Graphic view of flow analysis indicating an excess amount of drag at the frontal surface of the thrusters. Very little drag was exhibited near the surface (0.18465 N) of the aluminum frame.

To verify the data obtained through the simulation, we calculated drag using the equation $\mathbf{F_d=1/2\rho v^2C_dA}$, where $\mathbf{F_d}$ **(N)** is the drag force, **ρ (kg/m^3)** is the mass density of the fluid, **v (m/s)** is the speed of the object, $\mathbf{C_d}$ is the drag coefficient for the surface (Flat plate=0.01 and sphere=.47), and **A(m^2)** is the reference area. It was determined that the drag on the aluminum flat bar frame was still significantly better. Our results differed slightly from the simulation due possibly to the variation between drag coefficients used by the simulation software and calculation.



Sample Drag Calculation
Fresh water @ 20 °c
Velocity: 0.30 m/s

Aluminum Flat Bar
$F_d=1/2\ \rho v^2C_dA$
$F_d=(0.5)(999)(0.302)(0.01)(0.4)$
$F_d=0.60$ N

PVC Pipe
$F_d=1/2\ \rho v^2C_dA$
$F_d=(0.5)(999)(0.302)(0.04)(0.6)$
$F_d=3.6$ N

After testing, the company decided to construct the frame from aluminum flat bar. The box-shape frame measures 0.46m x 0.35m x 0.30m (L x W x H) and is open on all sides. The open-ended design provides sufficient space to easily mount thrusters, end effectors, and buoyancy and allows easy access to all mounted components for troubleshooting and maintenance.

Figure 7: Aluminum Frame. (A. Short, 2014)
Aluminum Grade 6061 Alloy Properties: Brinell Hardness = 95 HB, Tensile Strength = 290 MPa +/- , Yield Strength = 241 Mpa +/-

Aluminum flat bar proved to be lightweight, corrosion resistant, durable, and easy to cut and bend. In addition it combines high tensile strength, hardness, and temperature resistance with low water absorption. Once the basic shape was chosen, a complete model including thrusters, buoyancy, and the camera was drafted in SolidWorks. Further drag analysis was performed to see how fluid flow would be affected. We discovered that the entire model would yield a drag of -11.49N.

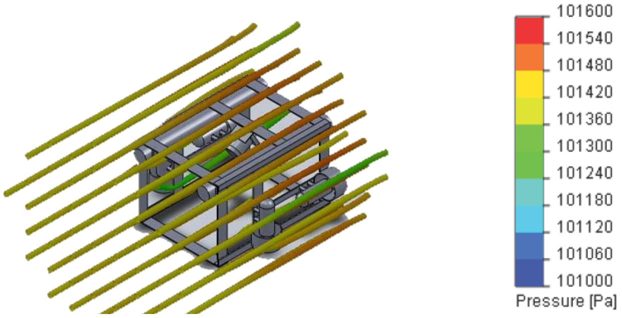


Figure 8: FloWorks Simulation – Isometric. (A. Short, 2014)
Isometric view. Pressure range 101280Pa – 101565Pa

Propulsion

An efficient propulsion system is a critical component in the design of a successful ROV. Our company required thrusters that were powerful, compact, lightweight and energy efficient. Cougar Robotics Inc. chose to examine two types of thrusters: a commercially available product, and a custom thruster designed by our company.

First, we selected the BTD-150 thruster available from Seabotix. Weighing only 350g in water, the thruster was equipped with a 12V Brushed DC motor, 76mm two-blade propeller, and Kort nozzle.

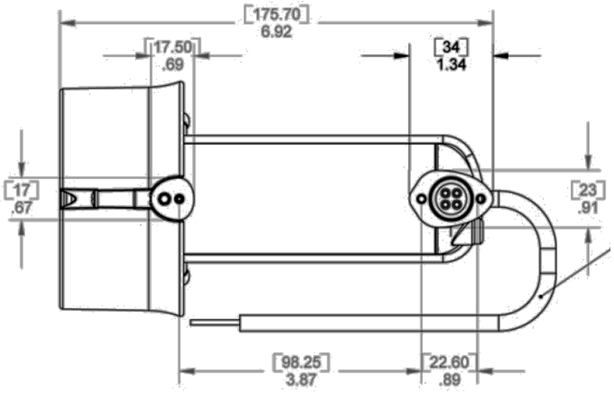


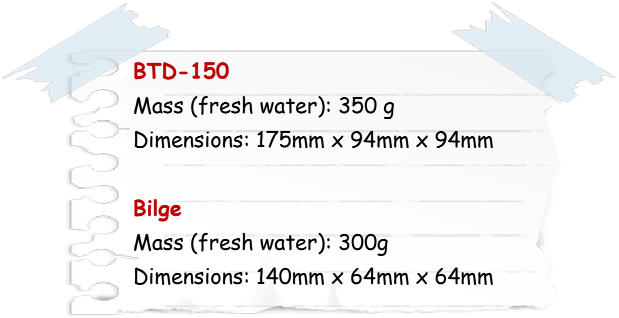
Figure 9: BTD-150 Drawing. (Rodocker 2007)
The thruster proved to be powerful, compact, lightweight, and efficient with a depth rating of 150m.

The second thruster selected was constructed from a 12 volt - 500GPH bilge pump. The motors were extracted from the bilge pump housings and dismantled. Mechanisms originally used to pump water were removed and replaced with a brass hub which was machined from 150mm diameter brass stock. A 40mm four-blade propeller with 4mm of pitch was secured using a 6mm set screw.

Figure 10: Bilge Pump Casing & Thruster. (A. Short, 2014)
Custom built thrusters were constructed from bilge pump motors. The casing was removed, and the motor fitted with a propeller.

Performance Analysis

To determine which thruster to use, our company performed a series of tests and comparisons. Upon inspection, the BTD-150 thruster appeared to be more robust despite being slightly heavier and larger throughout its dimensions.



BTD-150
Mass (fresh water): 350 g
Dimensions: 175mm x 94mm x 94mm

Bilge
Mass (fresh water): 300g
Dimensions: 140mm x 64mm x 64mm

Figure 11: Thruster Inspection. (I. King, 2014)
The data collected was an important factor in determining the choice of thruster.

To measure performance, a small scale Bollard test, consisting of a spring scale and lever, were used to determine the continual thrust exhibited by each thruster. As well, an ammeter was used to measure the current drawn in air and while under a load. It was found that the BTD-150 outperformed the bilge pump system. The Seabotix thrusters produced significantly more force, being almost three times more powerful. In addition, the current drawn by each of BTD-150 thrusters was nearly half that of the bilge pumps. From our experimental data, it was determined that the BTD-150 thrusters were clearly the optimal choice.

Bollard Test and Measured Data (water@ 20°C)			
Thruster	**Current**	**Current (Load)**	**Thrust**
BTD-150	0.46A	2.77 A	1.8 kg
Bilge Pump	0.74A	5.76 A	0.7 kg

Figure 12: Continual Bollard Test Results. (P. Dove, 2013)
Current was measured in air and under load in water at 20°C. The thrust was recorded under continual load.

After considerable analysis of the performance data and specifications it was determined that we would use the BTD-150 thrusters. Although our company took pride in producing and designing our own parts and components, it was agreed that the propulsion efficiency and mobility of the ROV could not be compromised.

Positioning of Thrusters

A test of all the electronics indicated that powering any more than four thrusters and end effectors at one time would be close to exceeding the 25 amp limit of the ROV. So, four thrusters (two for vertical translation, one for turning left, and one for turning right) were used to propel the ROV. The placement of the thrusters was crucial to provide stability and straight-line motion. The thrusters were positioned as low as possible to obtain a low center of gravity and to direct propeller backwash away from other sensors and end effectors. Two thrusters were placed on either side of the ROV to obtain vertical lift, and two thrusters were placed at the aft of the ROV to provide forward propulsion.

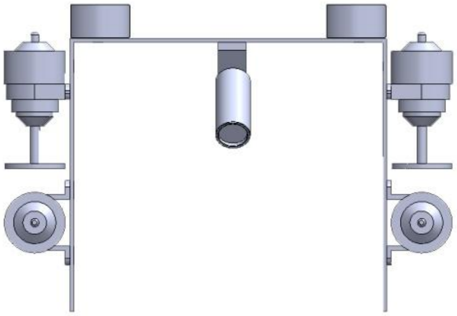


Figure 13: Thruster Placement - Front View **(C. Sawler, 2014)**
A total of four thrusters were used, two on either side of the ROV to provide horizontal and vertical thrust.

Ballast System

To control the vertical motion of the ROV, our company explored two possibilities. Initially, foam was considered for its buoyancy, but it was found that the foam would compress and lose flotation at the depths the ROV would be operating. Common polystyrene, for example, yields 10% deformation at 100 kilopascals of pressure. This deformation would compromise the stability of the ROV. So instead, our company went with a second option consisting of a section of vinyl downspout for flotation, and vertical thrusters to provide the necessary vertical translation.

The buoyancy was constructed from a 65cm x 6.4cm x 6.4cm section of vinyl downspout. The downspout was chosen because it would resist compression under extreme depths; it is also lightweight, durable and easy to mount on the ROV. Although, there are no commercially available end caps to fit the downspout, our company created our own, using a downspout coupler and fibreglass resin. The resin was poured into a mould and fitted to the end of the coupler provided a durable and airtight seal.

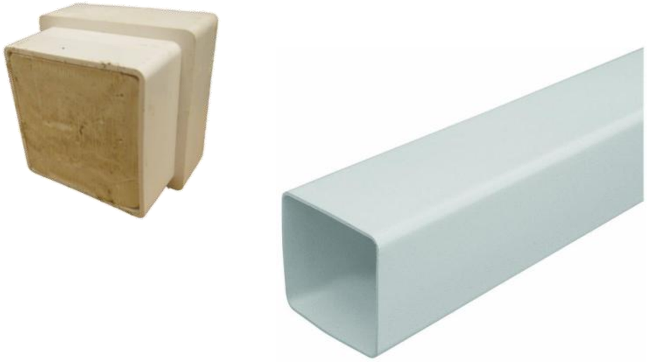
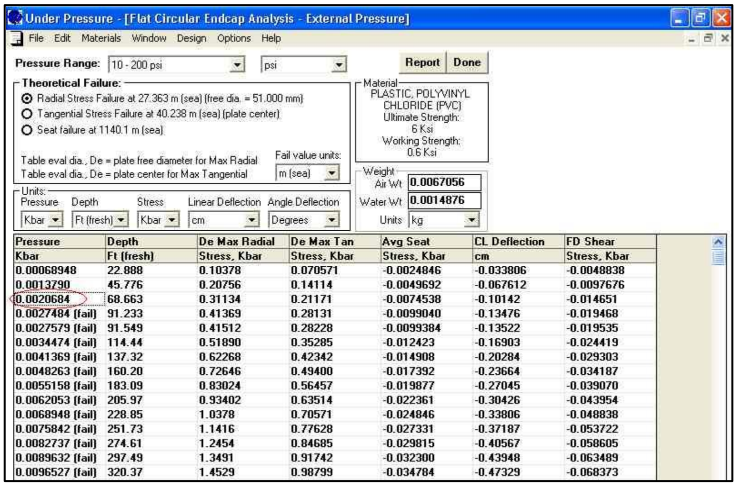


Figure 14: Downspout and Custom End Caps. (A. Short, 2014)
The buoyancy was constructed from downspout and custom end caps. It measures 65cm x 6.4cm x 6.4cm and has a depth rating of 9m.

There was much concern that the sides of the downspout or the end caps could possibly collapse at greater depths. To test this concern we used packaged software called Under Pressure 4.5, an engineering design tool to aid in the fabrication of pressure housings and vessels in the marine industry.

The software evaluates structural capabilities, deflections, and weights of common pressure vessels. It also reports stresses and deflections for external pressures over a user-selectable pressure range. Both the end caps and vinyl downspout were tested independently to determine their depth rating. The simulation reported that the vinyl downspout would indeed collapse before the end caps. The downspout failed at 19 meters below sea level experiencing a tangential stress failure at 0.0019013 kbar (plate center) of pressure. The custom end caps experienced a radial stress failure at 0.0021013 kbar (plate center) of pressure. This equates to 21 meters below sea level, which is 7m deeper than our tether allowed. A screenshot of Under Pressure can be seen on the next page.



Pressure Range: 10 - 200 psi | psi

Theoretical Failure:
● Radial Stress Failure at 27.363 m (sea) (free dia. = 51.000 mm)
○ Tangential Stress Failure at 40.238 m (sea) (plate center)
○ Seat failure at 1140.1 m (sea)

Table eval dia., De = plate free diameter for Max Radial
Table eval dia., De = plate center for Max Tangential
Fail value units: m (sea)

Material
PLASTIC, POLYVINYL CHLORIDE (PVC)
Ultimate Strength: 6 Ksi
Working Strength: 0.6 Ksi

Weight
Air Wt 0.0067056
Water Wt 0.0014876
Units kg

Units:
Pressure: Kbar
Depth: Ft (fresh)
Stress: Kbar
Linear Deflection: cm
Angle Deflection: Degrees

Pressure Kbar	Depth Ft (fresh)	De Max Radial Stress, Kbar	De Max Tan Stress, Kbar	Avg Seat Stress, Kbar	CL Deflection cm	FD Shear Stress, Kbar
0.00068948	22.888	0.10378	0.070571	-0.0024846	-0.033806	-0.0048838
0.0013790	45.776	0.20756	0.14114	-0.0049692	-0.067612	-0.0097676
0.0020684	68.663	0.31134	0.21171	-0.0074538	-0.10142	-0.014651
0.0027484 (fail)	91.233	0.41369	0.28131	-0.0099040	-0.13476	-0.019468
0.0027579 (fail)	91.549	0.41512	0.28228	-0.0099384	-0.13522	-0.019535
0.0034474 (fail)	114.44	0.51890	0.35285	-0.012423	-0.16903	-0.024419
0.0041369 (fail)	137.32	0.62268	0.42342	-0.014908	-0.20284	-0.029303
0.0048263 (fail)	160.20	0.72646	0.49400	-0.017392	-0.23664	-0.034187
0.0055158 (fail)	183.09	0.83024	0.56457	-0.019877	-0.27045	-0.039070
0.0062053 (fail)	205.97	0.93402	0.63514	-0.022361	-0.30426	-0.043954
0.0068948 (fail)	228.85	1.0378	0.70571	-0.024846	-0.33806	-0.048838
0.0075842 (fail)	251.73	1.1416	0.77628	-0.027331	-0.37187	-0.053722
0.0082737 (fail)	274.61	1.2454	0.84685	-0.029815	-0.40567	-0.058605
0.0089632 (fail)	297.49	1.3491	0.91742	-0.032300	-0.43948	-0.063489
0.0096527 (fail)	320.37	1.4529	0.98799	-0.034784	-0.47329	-0.068373

Figure 15: Under Pressure Screen Shot. (P.Dove 2014)
The screen shows a radial stress failure experienced by the end cap at a depth of 21m. The software is useful for analyzing structural capabilities, deflections, and weights of pressure vessels

Since our ROV is totally dependent on its thrusters for vertical motion, it was important that the ROV remain stable (neutrally buoyant) while the thrusters are not in operation. This would require that the net vertical force experienced by the device, while the vertical thrusters are not operating, be as close to zero as possible.

To accomplish this state of neutral buoyancy, the gravitational force experienced by the ROV had to be equal to the buoyant force. Using Archimedes's Principle, it was concluded that the weight of the water displaced by the ROV must equal the weight of the ROV. Next, we determined the approximate volume of vinyl downspout needed to displace this same amount of water. Knowing the mass of the ROV and the density of water allowed us to calculate the approximate length of downspout needed to satisfy this requirement.

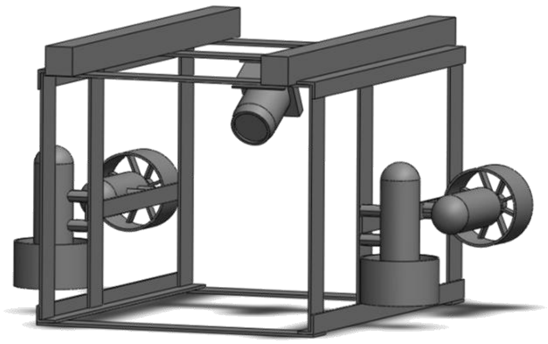


Figure 16: Buoyancy System. (C. Sawler, 2014)
Downspout was used as flotation and was positioned along the top edges of the ROV. Force of buoyancy measured 4.1 N

The bouyancy was placed along the edges of the frame, and the bulk of the mass (consisting of thrusters) was placed near the bottom of the ROV. This allowed maximum separation between the center of gravity and center of bouyancy to allow the stability and stiffness to be able to do its work.

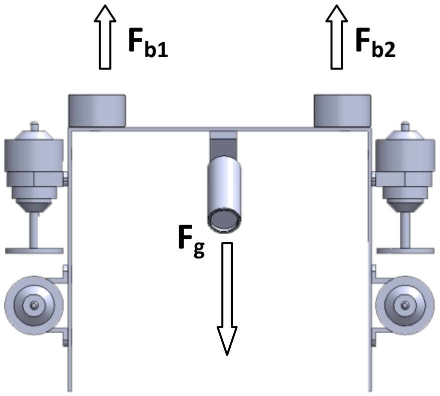


Figure 17: Net Force Diagram. (C. Sawler, 2014)
To achieve vehicle stability the flotation pack and mass are separated as far as possible. In effect, this design feature separates the center of buoyancy and ROV center of gravity.

Electrical System: Power Cable/Controller/Tether

The electrical system of ROV *Argo* was completely custom-designed and assembled by our company. It consists of the power cable, controller, end effectors, and tether. All systems have a 12 volt DC rating and satisfy the MATE competition safety guidelines.

Power Cable

The power cable was constructed from a 12-2 copper wire, a set of banana plugs, and a fuse. The cable is detachable from the controller allowing easier storage. A 25 amp blade fuse was placed on the positive side of the cable near the battery. In the case of increased current flow due to a short circuit, overload, or device failure, the fuse will blow and protect both the operators and ROV from injury.

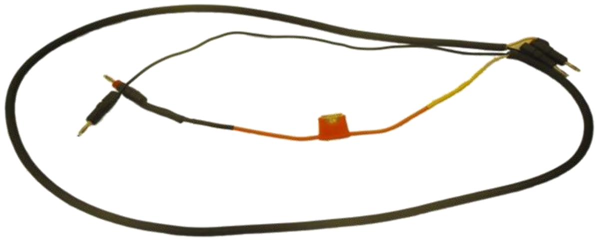


Figure 18: Power Cable. (A. Short, 2014)
The power cable consists of banana plugs and 25A blade fuse.

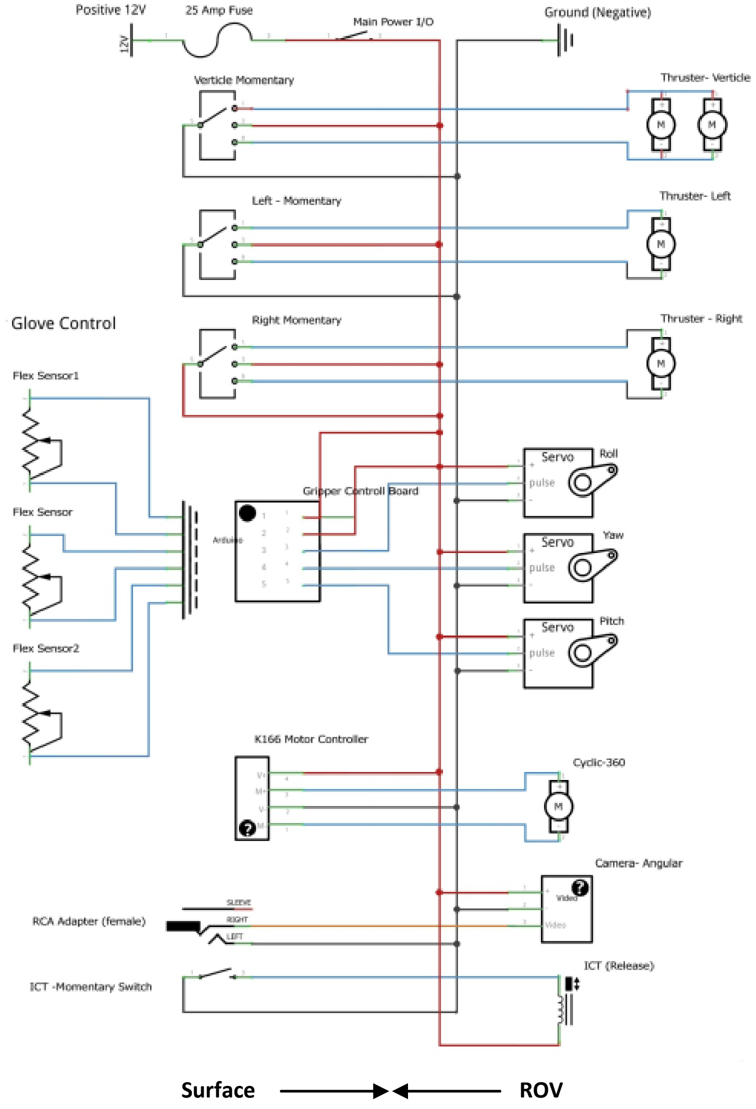


Figure 19: System Integration Diagram –SID. (C. Clarke, 2014)
Electrical schematic on ROV Argo indicating surface controls left and ROV right.

Controller

When designing the control system, the company chose a manual based system of momentary switches. This decision was based solely on simplicity and the possibility of troubleshooting in the event of a failure during competition. Various designs were drafted in SolidWorks and fitted with required components. Once the basic design was chosen, a console was created from aluminum since it provided a sturdy lightweight surface to mount switches and other electronic components. Inside the controller, we mounted two nickel-plated brass buss bars to serve as a tie point for the positive and negative terminals. An ammeter was added to monitor the amount of current drawn by the system, and a voltmeter was placed across the power terminals to read the voltage. A single dipole kill switch was added to shut down power immediately in case of emergency. To control the motion of the ROV, three two-way momentary switches were used. One switch operates both vertical motors and two separate switches control horizontal thrust and turning. Several momentary switches were also included to operate various end effectors.

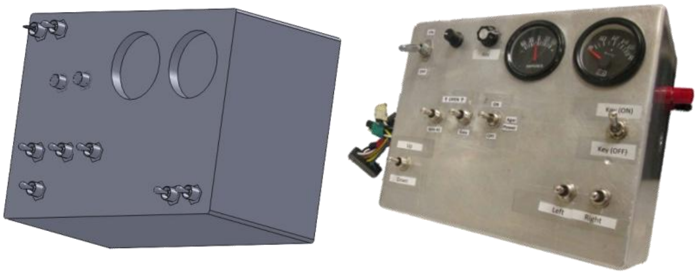


Figure 20: Controller CAD and final production. (A. Short, 2014)
The controller consists of momentary and binary switches, meters, a K-166 bi-directional board, and a CMM-2 Speed controller.

In addition, we have installed a K-166 bi-directional DC motor controller to operate one of the end effectors, the Cyclic-360. This controller allows us to manipulate the speed of a DC motor in both the forward and reverse direction using pulse-width modulation (PWM). The range of DC motor control is from fully OFF to fully ON in both directions. Turning the pot in the other direction causes the DC motor to spin in the opposite direction. The center position on the pot is OFF, forcing the motor to slow and stop before changing direction.

Figure 21: K-166 Motor Controller. (A. Short, 2014)
Uses Pulse PWM to maintain motor torque. Max. 32VDC operation for controller. IRFZ44 Mosfets can handle up to a maximum 49amp.

A UCMM-2 DC motor speed governor was also installed to limit the operation speed of a second end effector, the payload gates. The gates are used to seal off the payload bay once the ship debris has been collected. Two momentary switches will operate the gates independently and, by adjusting the pot on the speed controller, the power to each motor will be varied.

Figure 22: UCMM-2 Speed Controller. (Uxcell 2014)
High torque, low heat DC motor controller. The fuse type is 5x20m. As well it has a 10kΩ resistance.

Tether System

The tether (umbilical) of an ROV is the most important feature since it provides the only communication link between topside and the ROV. Our company has developed a unique modular tether system consisting of a primary tether, which operates the ROV and end effectors, and a secondary tether connected to the Environmental Collection Tool (ETC). In case of failure, any individual component of the tether may be replaced. This feature reduces cost and down time. The complete tethers system measures 15m and weighs 2.4kg.

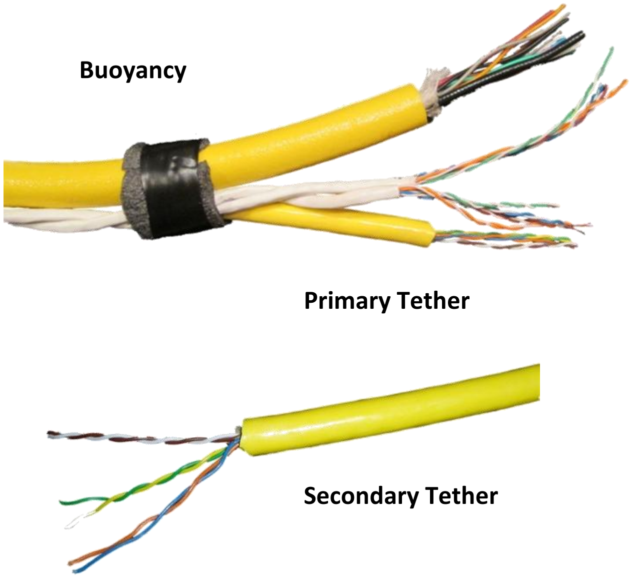


Figure 23: Primary and Secondary Tethers. (A. Short, 2014)
Both tethers measure 15m and are neutrally buoyant.

Primary Tether

The primary tether is the main lifeline to the ROV and consists of four different cables. The main cable provides power to the propulsion system, select end effectors, and the camera. It consists of six pairs of 24 gauge insulated wires used to control end effectors, a coaxial video cable, and three pairs of 20 gauge wires to power the thrusters. A second cable, consisting of three pairs of 24 gauge wires, is used to power the servos used on the robotic gripper. Also, two Cat-5 network cables were used as a means to transfer signals and control the gripper. To achieve neutral buoyancy, foam has been added at each meter along the length of the tether.

The secondary tether featured on ROV *Argo* was awarded to our team at the International Competition 2011 by VideoRay. The tether is neutrally buoyant and consists of three pairs of 20 gauge wires. It is connected directly to the ECT which is used to power the agar collection tool and to transmit signals from the salinity test.

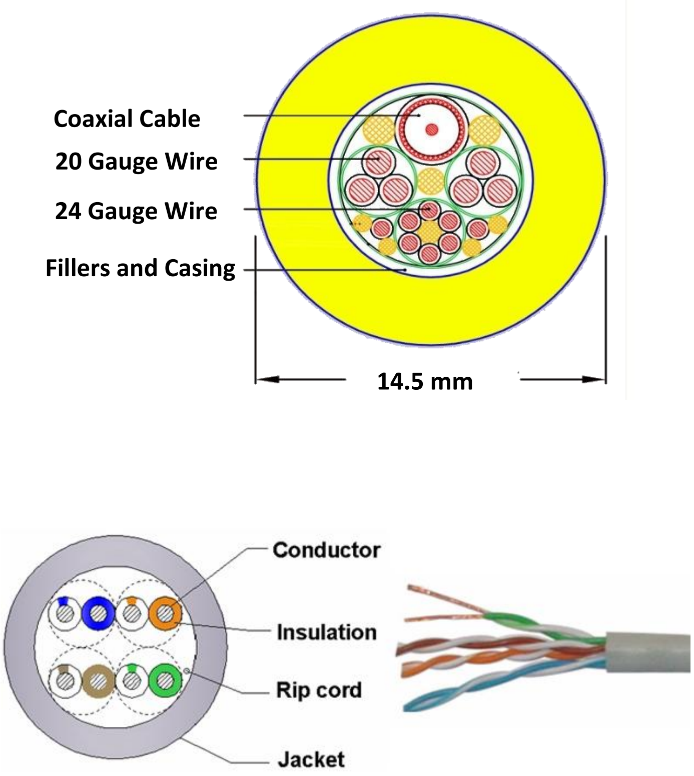


Figure 24: Tether – Cross Section and Spliced
Wire gauge is a critical component of tether choice. Larger gauge wire improves power transmission but limits tether flex.

Our company has also developed a new and innovative way of mounting the tether to the ROV. A universal GPS mount, positioned on top of the ROV, allows for easy turning, precise movements, and substantially increased maneuverability. This technique permits a freely moving but secure attachment of the tether to the ROV. In addition, the tether system may be easily detached if needed. This added feature proved to be most beneficial. It makes for easy storage and unpacking of the system. As well, each employee can work on separate parts of the ROV, preparing each individual part at a faster rate.

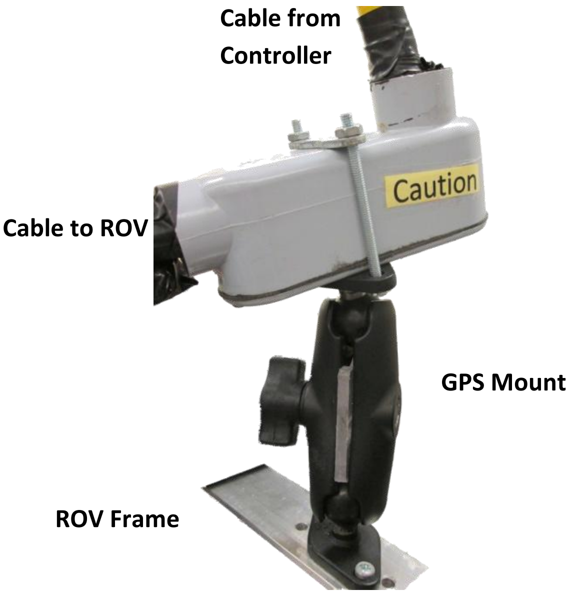


Figure 25: Tether Connection System. (A. Short, 2014)
The connection system is based on two swivels which allow free tether range.

Cameras

ROV *Argo* is equipped with two cameras. The frontal camera is directed at the tool bay and provides sufficient view of effectors. It is also the main camera used during the mission and offers an exceptional view. A second camera is placed at the aft of the ROV and may be used to guide it in reverse or view the path of the trailing tether.

The frontal camera is a locally produced camera from SubC Control. They were chosen because they produce high quality products and were able to provide immediate assistance when needed. Angler model camera entails digital noise reduction, back light compensation, and highlight compensation which results in a clear, sharp image. The camera has an underwater view angle of 85 degrees and the ability to operate in low light conditions of 0.0001 Lux. It boasts a resolution of 1020 x 580 pixels, a sapphire lens, and the ability to operate at depths up to 500m.

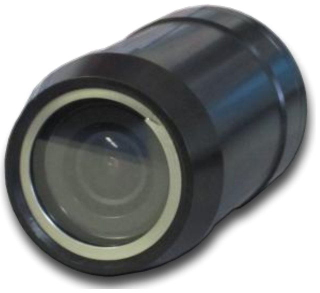


Figure 26: Main ROV Camera. (A. Short, 2014)
The main camera was constructed by Sub C Control. This local company has worked closely with our team.

To place the camera on the ROV we developed a simple formula to determine how far back the camera needed to be for optimal viewing. $\mathbf{L=x\cdot\cot\theta}$, where $\mathbf{w}$ is the width of the ROV, $\mathbf{x=1/2w}$, $\mathbf{L}$ is the distance from the lens to the front of the ROV, and $\boldsymbol{\theta}$ is the field of view angle divided by 2.

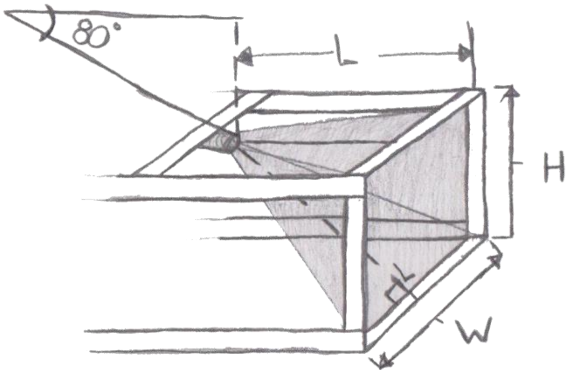


Figure 27: Camera Placement. (B. Snow, 2014)
The Equation L=x·cotθ was derived to determine the optimal camera location.

The second camera placed at the back of the ROV was constructed from a Jetview JF-CM-26B video camera and a custom waterproof casing. The casing was created using a section of PVC pipe and modified endcap sealed with a clear acrylic lens.

Figure 28: Custom Rear Camera. (A. Short, 2014)
The Jetview camera with its custom-designed case offers a view from the rear of the ROV.

Sensors

ROV *Argo* is equipped with a variety of custom-designed sensors to enhance performance and improve its functionality for the successful completion of its goals. These sensors are 100% interchangeable due to our custom-developed plug and play system which has been integrated into the ROV.

- One of the first sensors we developed was a **touch sensor** consisting of a microcontroller, a softpot (linear potentiometer) and a LED. We have used the Arduino Uno which has 14 digital input/output pins, six of which can be used for pulse-width modulation outputs, six analog input/output pins along with 5V and 3.3V output pins, and two ground pins. Arduinos use a custom programming language that is based on C++.

Figure 29: Arduino Uno. (A. Short, 2014)
The Choice microcontroller used by Cougar Robotics.

We have programmed the Arduino to read the analog signals produced by the softpot and adjust the brightness of a LED accordingly. This detachable and multiple use sensor is an optional feature and can be used for multiple tasks. During the initial design stages, the system was connected using the bread board shown below.

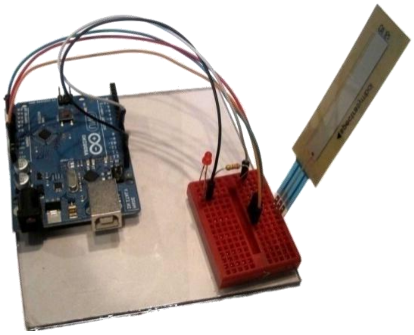
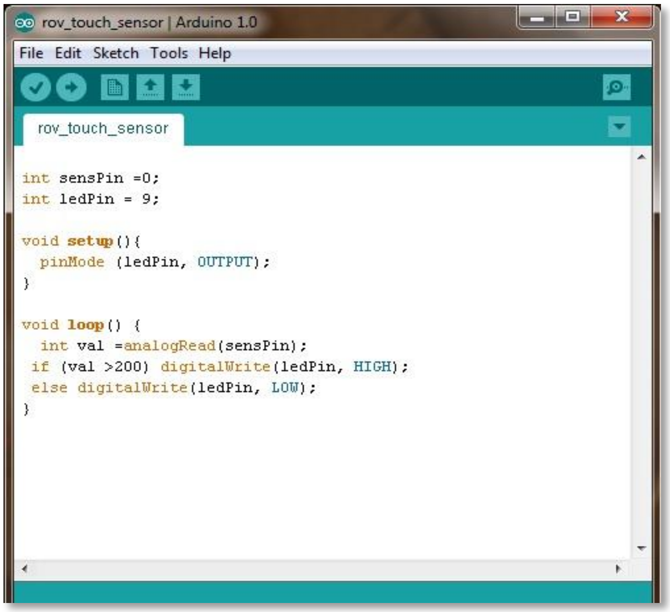


Figure 30: Touch Sensor. (A. Short, 2014)
Optional touch sensor at the developmental stage.

Programming the Arduino involves defining each pin in use and labeling it as either input or output. A loop is then created which tells the Arduino the steps it must follow. For example, in the program below, we tell the Arduino to read the value produced by the sensor, and if it is greater than 200, the LED will be at its maximum brightness, dimming as the value approaches zero.



```
int sensPin =0;
int ledPin = 9;

void setup(){
  pinMode (ledPin, OUTPUT);
}

void loop() {
  int val =analogRead(sensPin);
 if (val >200) digitalWrite(ledPin, HIGH);
 else digitalWrite(ledPin, LOW);
}
```

Figure 31: Programming the Arduino. (K. Clarke, 2014)
The touch sensor was programmed to trigger a LED at a specified limit.

Since knowing depth is a requirement for piloting an ROV, the company has fitted the ROV with a depth finder.

- The **depth finder** was custom built from a pressure transducer dismantled from a lab pressure sensor. The transducer consists of three wires, one of which reports a voltage to the surface. This voltage is measured topside (independent of the controller) using a multimeter and has been calibrated to report on the depth of the ROV.

Figure 32: Depth Finder. (A. Short, 2014)
Consisting of a pressure transducer and multimeter at top side, the depth sensor is a vital aid to ROV navigation.

- In order to hear its surroundings, the ROV is equipped with a **hydrophone** which was constructed using a microphone, 0.025m OD PVC pipe, and a 0.001m diameter plate. The microphone was placed inside the pipe, sealed on one end with epoxy, and covered on the other end with a vinyl cap.

  To identify noises, Audacity software was used. It allows the user to hear sound and also to view the audio frequencies recorded by the hydrophone.

Figure 32: Hydrophone. (A. Short, 2014)
The optional hydrophone is one of the many available plug and play sensors.

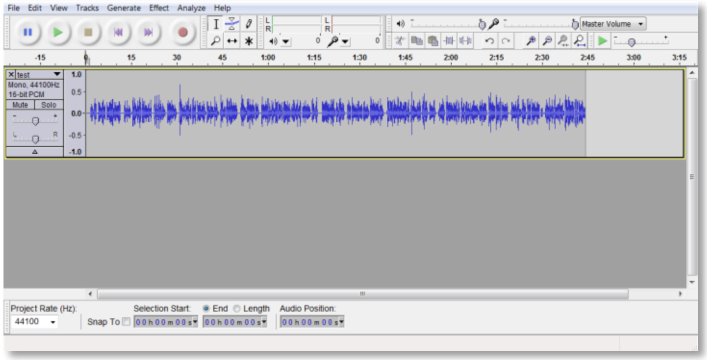


Figure 33: Audacity Screenshot. (P. Dove 2013)
Audacity allows the pilot to hear noises from the hydrophone. It also visually displays audio frequencies on a monitor.

- The ROV is equipped with a Plug and Play **temperature sensor** constructed from a Positive Temperature Coefficient (PTC) thermistor and a PVC casing. The thermistor is wired through the tether to a multi-meter at topside. The resistance is read, and a calibration chart converts it to a temperature.

Figure 34: Temperature sensor. (A. Short, 2014)
The optional temperature sensor constructed from a PTC thermistor and multimeter at topside.

Features to Accomplish Missions (Payload Description)

The MATE ROV competition challenged our company to develop a specialized ROV to survey shipwrecks and collect samples for scientific study.

Tool #1: Environmental Collection Tool (ECT)

Figure 35: Environmental Collection Tool (ECT). (A. Short, 2014)
Specifications: Retrieve agar and test salinity. Voltage 12V, Mass: 2.3 Kg. Dim. 12cm x 4cm x 5cm. Detachable system.

The Enviro Collection Tool (ECT) will be used for **retrieving the agar sample and measuring the salinity of water samples**. To retrieve the agar sample, a versatile tool was needed that could collect the sample regardless of consistency. After considerable contemplation, our company designed a comprisable tool to complete this task. The first of this two-part tool is constructed from a large piece of CPVC pipe with several copper pipes placed inside. The system of pipes is spring loaded and is released when the pin attached to a motor is removed, propelling the pipe system at a very high velocity towards the agar and retrieving the sample. The second part of this tool consists of a 12V power adaptor which is wired through the tether and connected to a two pronged trailer plug so that the conductivity, and therefore salinity, can be measured. As previously mentioned, this tool comes with its own tether. We wanted to make sure that we could remove this tool from the ROV. Because it is quite large, it is not wired through our original tether but instead, has its own tether and controller to allow for easy removal when both tasks have been completed. Finally, the ECT has been made positively buoyant so that when it is removed it will float to the surface to be retrieved later in the mission.

Tool #2: The Cyclic-360

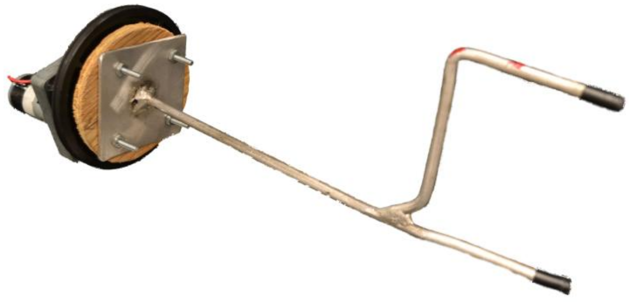


Figure 36: Cyclic-360. (A. Short, 2014)
Specifications: 12V DC Motor, UCMM Speed controller, mass: 1.2 Kg, Dim. 12x3x4x5 cm

The Cyclic 360° is our simplest and possibly our most effective end effector. It will be used for multiple tasks, including **opening and closing the cargo container, and retrieving the anchor line and sensor string**. This tool is constructed from a 12 inch long fork-shaped aluminum arm extending from the inside of the ROV. The base of the arm is connected to a 12 volt DC Motor, which is controlled by a K-166 bidirectional motor controller, giving it 360 degrees of rotation.

Tool #3: The Gates

To **collect the containers and plate** we will scoop them inside the payload bay of the ROV. As mentioned earlier, the bay is sealed off by using two acrylic gates attached to separated DC motors. The motors and motion of the gates are controlled by two bi-directional switches and a UCMM-2 speed controller.

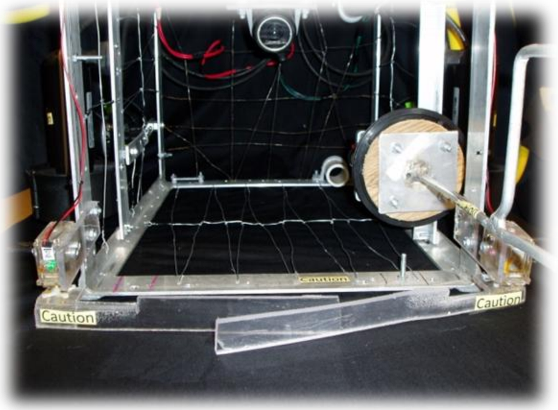


Figure 37: Payload Gates. (A. Short, 2014)
The gates are independently operated to direct trash into the ROV payload bay.

Tool # 4: The 'Tape'

Figure 38: Measuring Tool. (A. Short, 2014)
A unique feature of the tool is the swivel which allows the ROV to measure vertical and horizontal distances without switching tools.

To measure the length of the shipwreck the company has constructed a tool ingeniously named 'the tape.' It consists of a double-sided retractable tape measure and a 20cm diameter ring used to catch the bow post of the ship. The tape is attached to an aluminum bar by a bearing removed from a dolly wheel. The bearing allows the tape to rotate when switching from horizontal to vertical measurements. The pilot flies the ROV directly over the post at the bow of the shipwreck and catches it with the ring. The ROV then continues to the stern of the ship where it can take a measurement. Once a measurement is taken, the ROV surfaces, allowing the ring to slip up over the bow post and retract to its original position. The process is repeated to measure the width and height.

Tool # 5: The Robotic Gripper

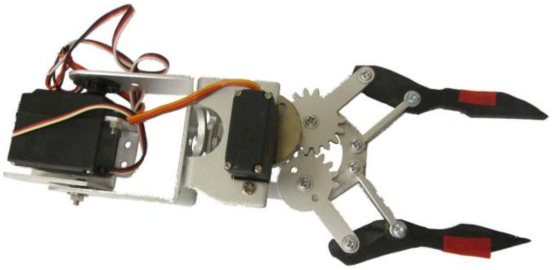


Figure 39: Robotic Gripper. (A. Short, 2014)
The gripper is operated by a selection of controllers and is programmed using C++ language.

One of the most versatile tools on the ROV is the robotic gripper. The arm has three degrees of freedom and can be used to **collect the containers and plate**. The claw of the robotic gripper has a clutch which consists of two metal plates with a spring in between. Its main job is to make the claw come together tightly to ensure a firm grasp onto whatever needs to be moved. The clutch also prevents the gears inside of the servo from stripping.

The wrist of the robotic gripper consists of two servos and aluminum joints. One servo allows the wrist to flex, and the other allows the wrist to rotate. Each of the three servos on the robotic gripper uses three wires with one each for power, ground, and command. The command wire runs back to an Arduino micro-controller for finite control over the gripper's movements.

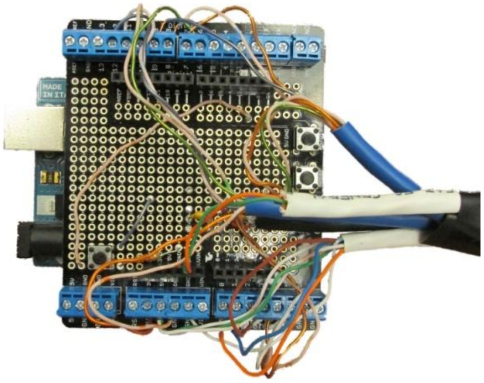


Figure 40: Logic Board. (A. Short, 2014)
Custom Logic Board consisting of an Arduino UNO and Proto-board to switch between control devices.

The gripper has its own controller and tether. As mentioned previously, the tether is made using one main cable tether and two Cat-5 wires. One of the Cat-5 wires leads back to the power board which supplies power to the servos individually. The second Cat-5 wire leads back to a logic board. The logic board is the interface between the Arduino, the selected controller and the servos.

The custom logic board and the custom power board are two of our key design features. The logic board is an Arduino compatible prototype board which enabled us to build a custom solution for our multiple control options and interface these to the Arduino. An important feature of this logic board is that it allows us to change our controllers by pressing a button which has been installed on it. The board takes the signal from the selected controller, passes it to the Arduino, and then passes the output from the Arduino to the servos, creating movement along the arm.

The power board is crucial for power management along the three servos in the arm. Each servo requires 4.8 to 6 volts of power while our battery supplies 12 volts. The power board is directly connected to the battery and has 3 voltage regulators that are used to step down the voltage from 12 volts to 5 volts each. The power board also has capacitors placed before and after the voltage regulators to act as filters and help handle spikes in power.

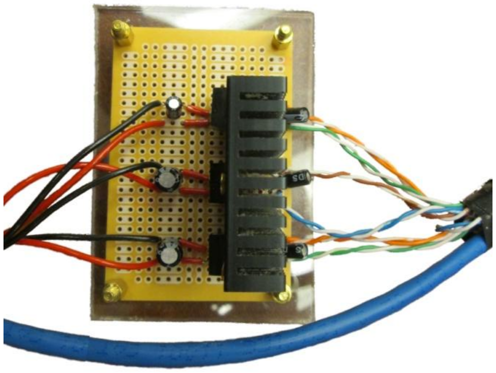


Figure 41: Power Board. (A. Short, 2014)
The custom power board steps the voltage down from 12V to 5V using voltage regulators. Each regulator has input and output capacitors used as filters.

The Robotic Gripper has three available controller options. The first available method of control is a rotary controller which uses three potentiometers, one for each of the three servos.

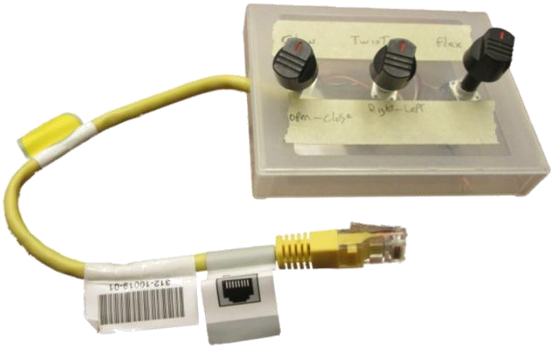


Figure 42: Rotary Controller. (A. Short, 2014)

The second controller is a Nunchuck for the Nintendo Wii. By using the built in accelerometer, we can rotate the wrist. The joy stick on the controller is used to open and close the claw as well as flex the wrist.

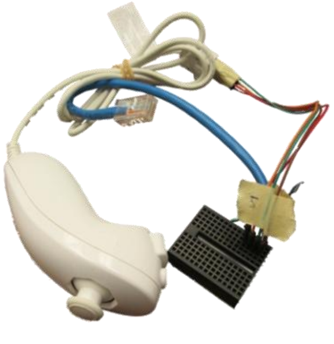


Figure 43: Nunchuck Controller. (A. Short, 2014)

The third controller option is a custom-made glove-based motion controller. An accelerometer was placed at the base of the thumb inside the glove to rotate the wrist, and two flex sensors were placed in the index finger and middle finger of the glove. These flex sensors are used to open and close the claw as well as flex the wrist.

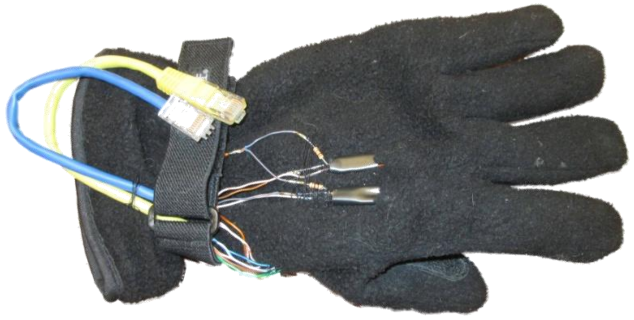


Figure 44: Glove control. (A. Short, 2014)
The custom glove control consists of an accelerometer and two flex sensors.

One of the reasons for building a component-based system is redundancy. Building the Arduino shield and a custom PCB for the power board gives us greater flexibility with dealing when any potential faults in the system. With this design, we can easily switch out components like controllers and control boards quickly on the fly.

Our gripper is programmed using the Arduino microcontroller environment. We used the standard Arduino C++ library and additional public domain libraries for the control of our accelerometer in the glove-based controller and the Nintendo Wii-Nunchuck. The program is written using the switch/case logic structure. Each controller has been assigned a number in the software and this number is used as the control for the switch structure. A push button on the logic board advances a variable in the software corresponding to the numbers assigned to the controller and the cases in the programming structure. Another important feature we included was a dead band. The dead band was used to help eliminate jitter among the servos in the arm (caused by minute changes in voltage) creating smoother operation.

The architecture of this system allows for the easy addition of controller options in both hardware and software. It also provides a more open system allowing for the quick replacement of parts suffering failure. Another consideration is that future upgrades would not require a wholesale change since individual components, such as the power board, can be replaced with an upgraded unit quickly and easily.

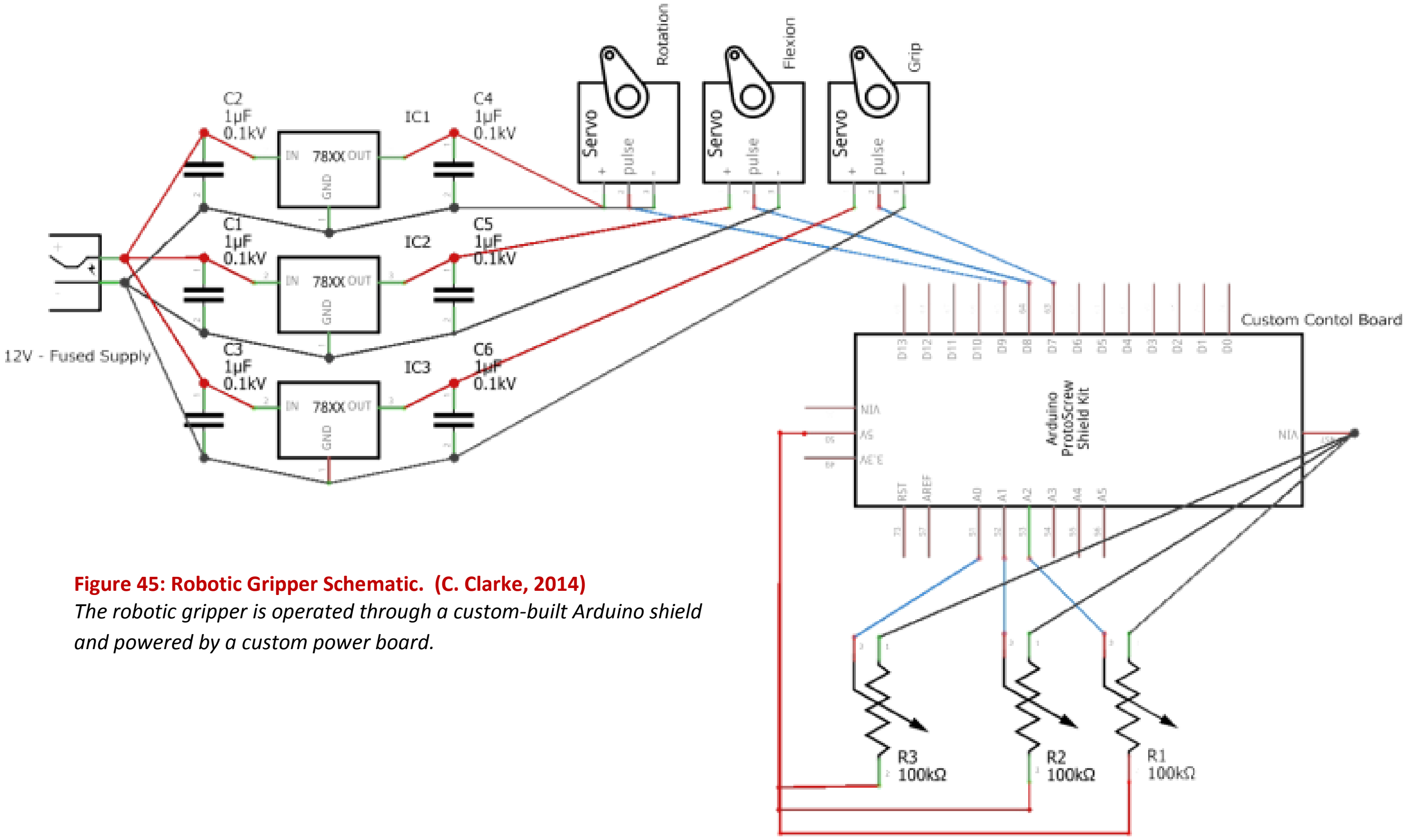


Figure 45: Robotic Gripper Schematic. (C. Clarke, 2014)
The robotic gripper is operated through a custom-built Arduino shield and powered by a custom power board.

Troubleshooting Technique

Throughout the entire project and build of ROV *Argo* our company experienced many problems and faced a number of failures. When we encountered a problem we used a three-step troubleshooting technique that we developed and found to be very effective. We first identified the affected area; secondly, we selected a probable cause and determined a solution; and lastly, we tested the solution.

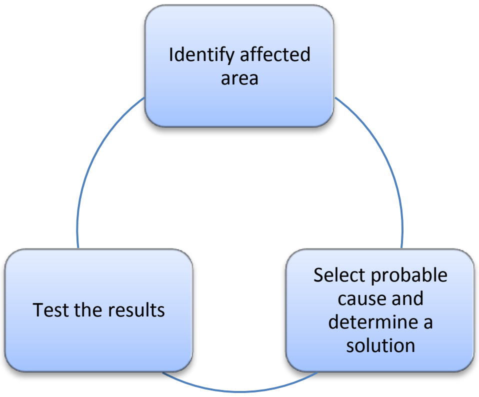


Figure 46: Trouble Shooting Process. (C. Sawler, 2014)
Three-step trouble shooting process developed and put into practice by Cougar Robotics Inc.

When constructing our ROV, we tested consistently the success of our components and the overall vehicle. Initially, the vehicle was completed, designed, and tested using SolidWorks. After production, the ROV was vigorously tested in our homemade test tank. If problems were discovered we immediately put our three-step troubleshooting technique into action. Due to our troubleshooting procedure, we believe we have not only solved and occasionally prevented problems, but we also were able to deal with any difficulties that arose quickly.

Figure 47: Testing the ROV in our test tank. (A. Short, 2014)

Challenges

When completing the requirements for MATE ROV's 2014 competition, Cougars Robotics Inc. encountered various challenges of both a technical and non-technical nature. One of the technical challenges faced was evident during the construction and programming of the glove control for the robotic gripper. During initial testing it was found that syncing the movements of the glove and gripper was quite difficult. The motion of the gripper was erratic and susceptible to excessive jitter. To solve this problem, we added a deadband to the logic board and rewrote the program to improve calibration limits of the flex sensors. The motion of the gripper was much more fluid and responsive to glove movement.

A non-technical challenge was apparent when trying to schedule meeting times for our team. Building an ROV demands a major commitment and hundreds of hours of time. Because many of our company members are actively involved in numerous school clubs and community events, finding a common meeting time was nearly impossible. To overcome this challenge we divided our team into various subcommittees which made scheduling of meetings much more manageable since it involved few people and less schedules to accommodate.

Lessons Learned

We learned so many lessons during this process that we could never record all of them. Prior to the competition, many of our team members had never had experience in a workshop, much less building an ROV. We learned many techniques that were pertinent to water-proofing, electronics, buoyancy, and propulsion as well as team work and much more.

One of the more useful technical skills that we acquired was the ability to operate all shop tools effectively. Prior to entering the workshop and using any of the tools in it, each team member had to pass safety tests specific to all of the different tools with no questions answered incorrectly. With the tests done, each member of the team began to master the usage of the shop's tools during the continuous construction phase of our ROV. As expected, these practical skills were quite useful and will prove to be very beneficial in other aspects of our lives as well. From future careers to future school courses to even household jobs, these skills will prove to be valuable to all of the members of our team.

Not all aspects of this ROV project were quite so technical. We also had to interact with people we did not know well in an often stressful and dynamic environment. We knew that successful completion of this enormous project would require thorough and effective teamwork. After much practice, our team perfected our ability to recognize and utilize each other's individual strengths. The ability to do so proved to be one of the most valuable interpersonal skills that we would acquire. This meant that all team members had their own specialization with the ROV. Whether it is Brooke with the graphic design of our poster board or Greg with general construction, the ROV would not have been successfully completed without the combined effort of each and every teammate. After many months of dedicated hard work, our team learnt many skills that were applicable not only to ROVs but also to aspects of our future lives.

Future Improvements

It would seem, regardless of how much time you have, there will always be elements which can be further improved. In years to come, more time would be invested in our frame design, thruster placement and positioning. A critical factor in designing and developing an effective ROV is to reduce overall drag and improve maneuverability. These factors are so important for our ROV's task completion that it is necessary to spend the additional countless hours needed on these parts. During the initial planning stages in coming years, further analysis of the ROV using COSMOS FloWorks will be conducted which will stream line the design and refine thruster placement. Optimal decisions could then be made leading to a successful developmental process and the completion of all tasks presented.

Reflections

To summarize our year at Cougar Robotics, it's hard to feel any other feeling aside from pride. While we have overcome our own set of difficulties this year, working on ROV *Argo* has been a success. The inspiration and mentorship we provided to a younger group of aspiring members has contributed to our company's growth as a group of individuals, sharing our acquired knowledge and receiving assistance in return. We had the opportunity to help and encourage our neighboring school's robotics team from the Scout level. These children visited our school to observe our meetings, watch our ROV complete tasks, learn about our creative processes, and receive advice and ideas. All this helped to develop our company's strengths, creativity and innovation, and enabled us to come up with a variety of ways to complete this year's mission. These strengths have been translated into the ROV we have created, which is strong and capable of completing each and every task presented to it. The main strength of ROV *Argo* for its clients is found within its detachable system where all components of ROV *Argo* are easily able to be removed and replaced in case of malfunction.

Figure 48: Mentoring the local Scout team. (A. Short, 2014)
Kyle Evans showing CMS Scout team member Holly Haines how to mount the robotic gripper.

Teamwork

The teamwork, determination, and dedication required to complete an ROV such as *Argo*, provides students with a valuable learning experience. To complete this project we needed all teammates to work to their full potential, utilizing their skills on every aspect of the ROV, the technical report, the presentation and the poster display. Specific jobs were assigned to be completed by groups of team members and by making a schedule of tasks. Our schedule included tasks to be done, ideal completion times, and what we planned to do when everything was completed. Throughout the building process we acquired knowledge and practical skills from this unique and exciting project. As a team we worked hard to develop and construct every aspect of ROV *Argo* ourselves, especially the electrical components such as the tether, controller, our robotic gripper, and our detachable agar mechanism. In the end we enjoyed a great extra-curricular activity which brought a group of different individuals with similar interests together. New friendships were formed, while innovative ideas were brought to the table. We learned co-operation, perseverance, work ethic, and competitiveness as well as a sense of accomplishment as a result of this rewarding experience.

Safety

Cougar Robotics' philosophy is that safety is our top priority. **ROV *Argo* has been built to competition safety requirements.** Our company followed strict safety procedures when we were constructing the ROV and practicing with it. We ensured that proper safety equipment was worn at all times when constructing the ROV including well-maintained safety glasses.

Figure 49: Safety First. (A. Short, 2014)
The proper safety equipment was used while working on the ROV.

ROV *Argo* has a 25 amp blade fuse on its positive side as well as an emergency on/off switch in case of malfunction. There are no bare wires on the ROV which reduces the chance of getting an electric shock. The team took many different safety precautions and followed a Safety Checklist (Page 22). Guards were built to protect the motors from getting tangled during missions. These guards and warning labels have been added on all of the thrusters on the ROV. There are no sharp objects on ROV *Argo* which reduces the chance of injury during operation. Each person on the team received training on the correct use of all tools that were used during construction. A major safety procedure we follow is to keep a neatly coiled tether, not only because it is our lifeline, but to avoid any tripping hazards. While building the ROV, safety was always the first major concern.

Budget

Managing a project such as the construction of an ROV and financing a trip to the International Competition is an overwhelming task. Budgeting to build an ROV when most parts are either purchased from a foreign shop or removed from used equipment poses challenges. Initially, our company had budgeted $5000.00 to construct the ROV and at the end we did well coming $300 under budget. (Page 21). To help fund the project our company received a number of donations and in-kind contributions. The remainder of the required funds were collected through a series of fundraising events.

To travel to the International Competition, our company was very fortunate to receive funds through a government grant and industry contributions.

Acknowledgements

Cougar Robotics Incorporated would like to acknowledge and thank all of our sponsors for contributing to our team this year. We would like to thank local businesses such as Meridian Engineering, Sub-C Control, and Bonavista Auto-Salvage for their assistance with the project. We are grateful for the support received from all of our parents and our community, especially Mr. Rodney Short and Mr. Graham Manuel for their time commitment and efforts. Also, we would like to thank our mentors, Mr. Michael Spurrell, Mr. Bert Roberts, Mr. Christopher Clarke, and Mr. Nolan Porter for guiding us and teaching us everything we have learned along the way to get us here. Finally, we would like to acknowledge MATE and the Thunder Bay National Marine Sanctuary for organizing this competition and making this opportunity possible.

Contributors*[1]*:

Sub C Control
Craig's Locksmithing
Bonavista Auto Salvage
IBRD
Rodway`s Printing
Seal Pro
Marine Institute
The Wave Fitness Center
PEGNL (Bonavista-Burin)
Young's Refrigeration
International Paints
Meridian Engineering
Town of Clarenville
Government of NL

Note 1. These are contributors as of May 2014. An updated list will be posted at the competition.

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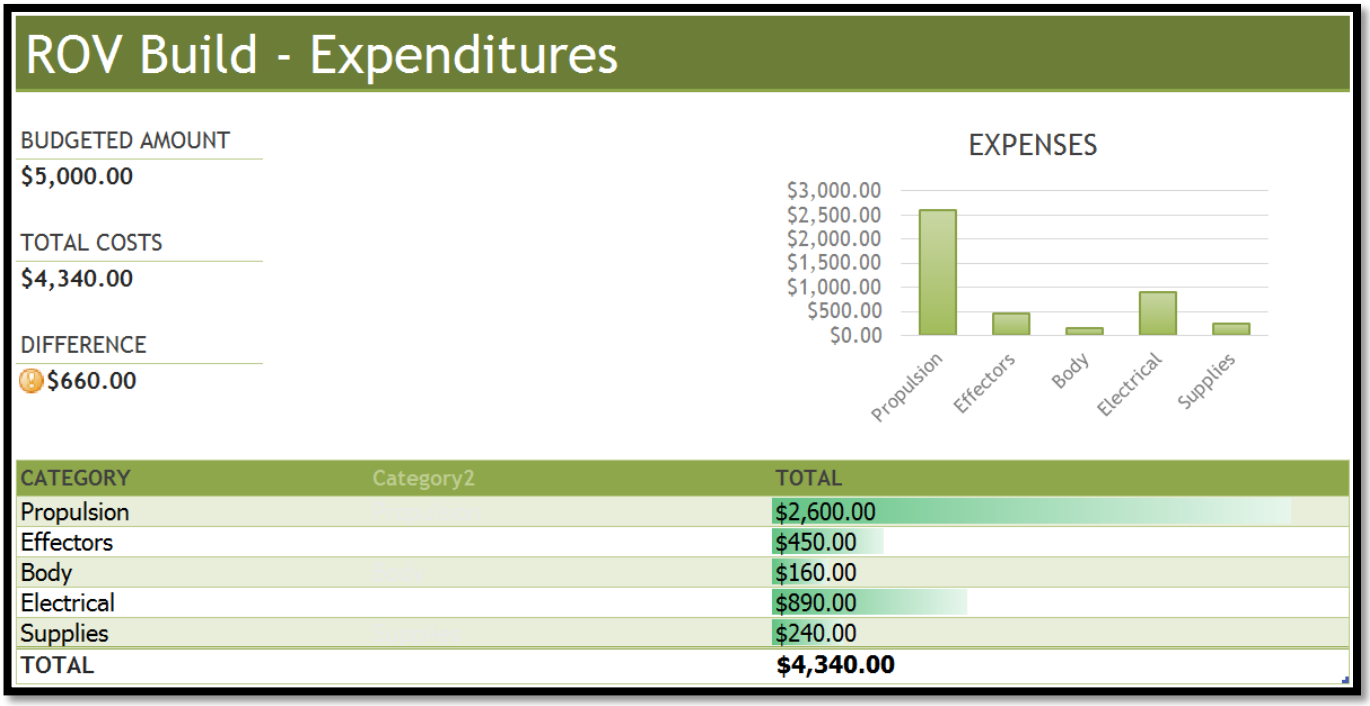
Bottom (Left-Right) - Michaela Barnes, Claire Sawler, Mackenzie Dove, Amy Short, Courtney Clark.
Top (Left-Right) - Greg Brockerville, Kyle Evans, Ian King, Chris Barnes, Kyle Clark, Patrick Dove.

Budget - ROV (Canadian Dollar)



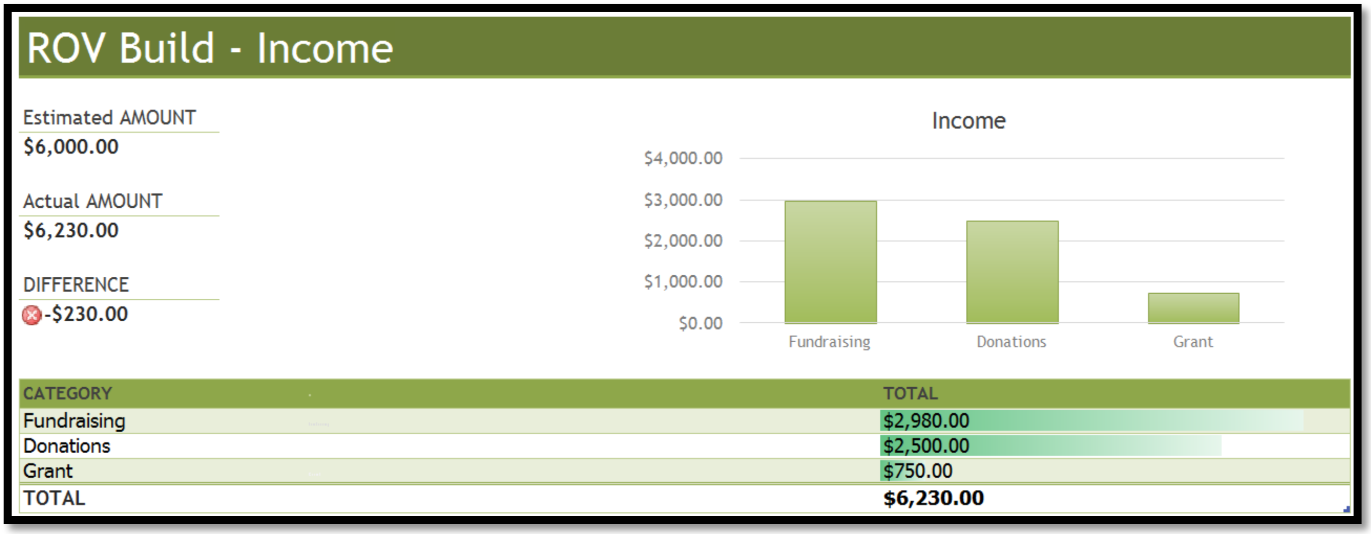
ROV Build - Expenditures

BUDGETED AMOUNT
$5,000.00

TOTAL COSTS
$4,340.00

DIFFERENCE
⚠ $660.00

CATEGORY	Category2	TOTAL
Propulsion		$2,600.00
Effectors		$450.00
Body		$160.00
Electrical		$890.00
Supplies		$240.00
TOTAL		**$4,340.00**



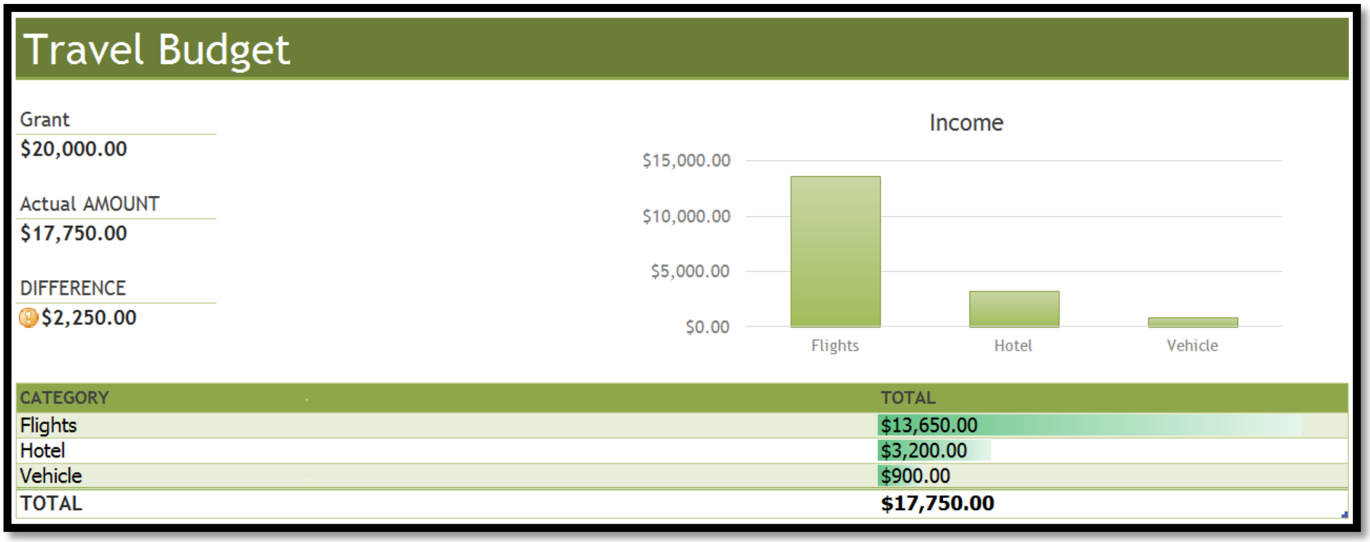
ROV Build - Income

Estimated AMOUNT
$6,000.00

Actual AMOUNT
$6,230.00

DIFFERENCE
⊗ -$230.00

CATEGORY	TOTAL
Fundraising	$2,980.00
Donations	$2,500.00
Grant	$750.00
TOTAL	**$6,230.00**



Travel Budget

Grant
$20,000.00

Actual AMOUNT
$17,750.00

DIFFERENCE
⚠ $2,250.00

CATEGORY	TOTAL
Flights	$13,650.00
Hotel	$3,200.00
Vehicle	$900.00
TOTAL	**$17,750.00**

Budget- Summary Specific (Canadian Dollar)

Expenditures			
Category	**Item**	**Donation**	**Amount**
Electrical	Switches/ Controller	Donation (Fair Market Value Listed)	$40.00
	Camera	Part Donation (Fair Market Value)	$200.00
	Tether		$150.00
	Program Boards	Donation (Fair Market Value Listed)	$120.00
	Sensors		$380.00
	Sub-Total		**$890.00**
Propulsion	BTD-150 Thrusters		$2450.00
	Bilge Pump		$100.00
	U – Brackets		$20.00
	Propellers		$30.00
	Sub-Total		**$2600.00**
Body	Lexan©	Donation (Fair Market Value Listed)	$60
	Flat Bar – Aluminum		$100.00
	Sub-Total		**$160.00**
Effectors	Pressure Gauge		$260.00
	PVC pipe	Donation (Fair Market Value Listed)	$30.00
	Magnets		$30.00
	Lexan ©		$80.00
	Aluminum		$50.00
	Sub-Total		**$450.00**
Supplies	Tape		$20.00
	Epoxy		$20.00
	Misc.		$200.00
	Sub-Total		**$240.00**
		Total	**$4340.00**

Income		
Fundraising	Cupcake Sales	$230.00
	Bottle Drives	$2200.00
	Car Wash	$550.00
	Sub-Total	**$2980.00**
Donations	Monetary	$2200.00
	In-kind	$300.00
	Sub-Total	**$2500.00**
Grant	Marine Start up	$750.00
	Sub-Total	**$750.00**
	Total	**$6230.00**

Safety Check List and Tether Management Protocol

Tether Management:

- ☐ Tether is stored in a safe location
- ☐ Tether is neatly coiled to prevent kinks and twisting
- ☐ The tether manager is mindful of loose tether while transporting
- ☐ Tether is always carried and transported by a sufficient number of people
- ☐ Ensure the tether is free of knots and kinks
- ☐ Ensure the tether is safely and securely attached to the ROV
- ☐ Refrain from stepping on tether to avoid injury and damage
- ☐ Always straighten tether prior to mission to improve maneuverability
- ☐ Release sufficient tether at the start of the mission to help the speed of the descent
- ☐ Make sure there is some slack, but not enough to result in tangling
- ☐ Do not pull on the tether
- ☐ After the mission is finished, carefully collect the tether and neatly coil it.

Construction Safety Checklist:

- ☐ Controller power switch is in OFF position
- ☐ ROV is disconnected from power source
- ☐ All personnel working on the ROV have proper qualifications for shop
- ☐ Propeller guards are securely fastened
- ☐ Be sure that no corrosive materials or exposed wiring is present
- ☐ Team members are using safety glasses/other appropriate safety equipment

Operational Safety Checklist:

- ☐ Controller power switch is in OFF position
- ☐ Fuse is in place (correct amperage)
- ☐ ROV is disconnected from power source
- ☐ Check ROV for hazards (loose bolts, cracks, buoyancy)
- ☐ No exposed wiring
- ☐ Complete resistance check
- ☐ Ensure guards are securely fastened
- ☐ Check end effectors for damage
- ☐ Step away from ROV and connect to power supply
- ☐ Check that all switches are working
- ☐ Designated personnel to place ROV in water and release
- ☐ Turn on power

System Integration Diagram (SID)