Hammerhead Technical Report

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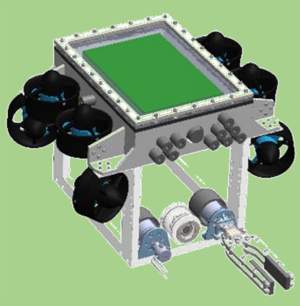


Abstract

Dalhousie Tigersharks Robotics is a new, innovative and learning focused company. We have had two years of experience with building and developing ROV's with this team. The outcome of last year's competition delivered us to 15th place with a robot completely build from scratch. This success is greatly complemented by our senior experienced team members that have 5 years of experience building ROVs.

This year's ROV, the Hammerhead came to light after the 2016 MATE competition in Houston when our pilot, Alex and the mechanical lead, Andrew had an idea to attach the thrusters directly to the enclosure. This thinking created a basis for a simplified ROV and complemented our company's design philosophy of simple, creative and powerful concepts. This philosophy along with the company's directive of creating learning opportunities for its employees is the basis of this year's robot.

The Hammerhead has been a great learning experience for many new team members and showed how many challenges there are with developing a ROV from scratch. Such as shop delays and manufacturing problem. The amalgamation of thrusters and enclosure was one of the feature design elements that helped reduce these challenges.

To accomplish the challenges put forth by this competition we have a developed resourceful tools. These include a multipurpose gripper with a wide extension and powerful grip, high quality cameras and measuring devices that are able to complete the designated tasks and are well suited for real world application.

Table of Contents

Company Introduction

The Dalhousie Tigersharks is a relatively new company that was revitalized from the previous dismantled company of the Privateers in 2015. The focus of this team has been to develop a new team structure that is focused on learning and gaining experience. This is achieved by researching and developing prototypes of ideas that the team would like to investigate. For example in 2016 the mechanical team designed our own shrouds and propellers to try to increase efficiency and power.

The team began with aspirations to design and build a functional robot from scratch and place within the top 15 at MATE competition. This goal was achieved by placing 15th in the competition but not without gaining many valuable learning experiences. These experiences are what has largely contributed to the design and development for this year's robot Hammerhead.

Our organization's philosophy is to promote learning and design simple, creative and powerful concepts. This philosophy is achieved by developing and building our own tools and enclosures to understand and prove concepts. The team decided to focus on an idea that was not used in 2016, this was to simplify enclosure. The focus on simplifying allowed the team to create ideas around the enclosure rather than coming up with a completely new design. We used the process of directed meeting and had focused brainstorms for problems such as the rotational tool that will be discussed later in the report. We then delegated tasks to a volunteer and paired them with a senior member to initiate a beneficial learning opportunity for our new members. The company also implemented tutorials for new members such as soldering, machine shop and Solidworks. These events gave new team members more confidence to contribute to the development of the new ROV.

Organizational Structure

Our company consists of 18 active members that separated into three main groups of mechanical, electrical and Logistics. The Logistics team was in charge of operation of the company which includes finances, scheduling meeting and build days and chair meeting to keep the company on schedule. The mechanical and electrical worked in unison to overcome the challenge of designing and manufacturing the ROV for survival in its underwater journey. The groups have two co-leads each that delegate tasks and keep the members on task. The organizational chart is displayed in figure 1.

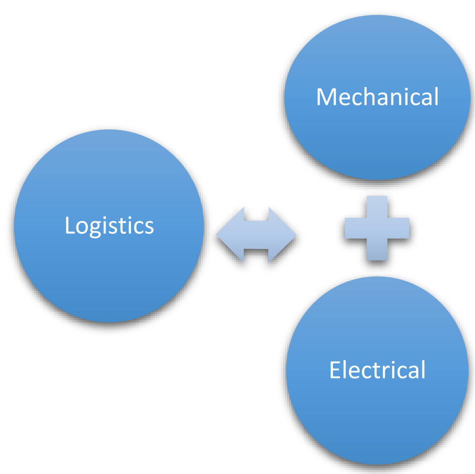


Figure 1- Company structure diagram

Long-Term Plan

The company's goal is to create an organization of innovative and enthusiastic individuals that would like to grow their skills in engineering and sustain the organization for future young engineers. This will be achieved through better recruiting tactics, more publicity and play an active role in engaging companies and the community.

Logistics and Organization

Project Management

To manage the arduous task of designing, building and demonstrating this ROV the logistics team is given the position to chair the meeting and build days. To ensure that ongoing effort was put into the development, a group discussion initiated the implementation of a set reoccurring meeting. Along with the position of chair the logistics team gives direction and pushes the team to stay focused and complete the task in an efficient manner. The organization undertakes this with group discussions and sets deadlines to move the project forward. These dates are placed into a schedule and followed up on the following meeting.

Scheduling

The company primarily utilized Gantt charts as a means of organizing and dedicating tasks to individuals. As seen in figure 2, the mechanical team Gantt chart outlines all of the needed elements to complete the ROV as well as the expected duration and resources allocated to each task. The Gantt chart helped us stay on task and complete the ROV in the designated time.

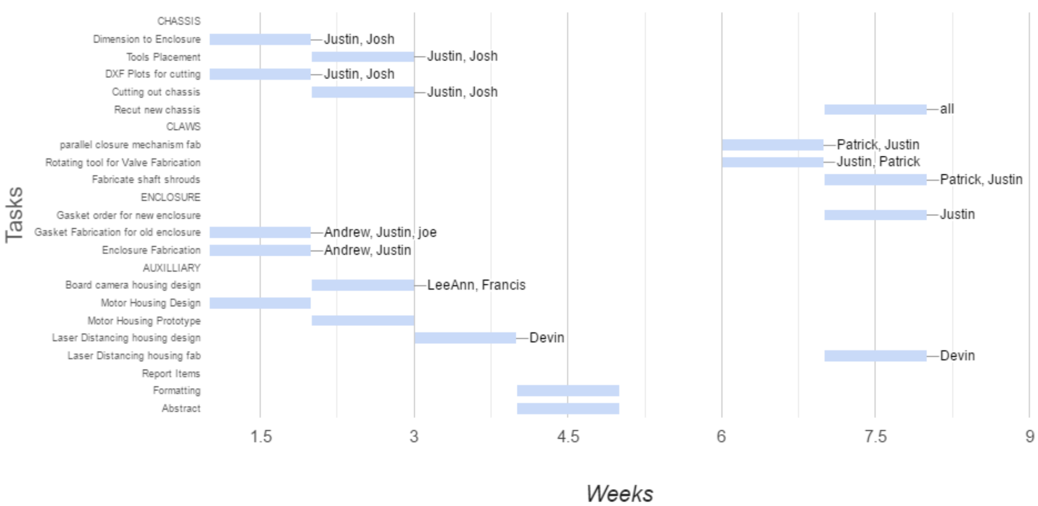


Figure 2- Mechanical team Gantt chart

Finances

Dalhousie Tigersharks is a corporation that is funded by sponsor donation. Our sponsorships are sorted out by tier. The Platinum and gold tier sponsors donated most of the operational budget as well as the capital cost of the robot. Guidance and experience was offered by the silver and bronze level sponsors, along with tool donations. Dalhousie Tigersharks would like to formally thank the following individuals and organizations for their enduring support. Our platinum tier sponsors where Shell Canada, and Dalhousie University who donated most of the capital cost. Our silver tier sponsors, Engineers Nova Scotia, offered to account for MATE registration fees. Our bronze tier sponsors, Jentronics Inc., the Aquatron Laboratory, and Survival Systems who donated parts, services and enduring support.

The budget for the 2016-2017 season was initially forecasted by the business group within Dalhousie Tigersharks. They forecasted a total robot expenditure of $3076.62 (CAD). The highest expenditure within the robot capital was that of electrical components totaling $1222.86 (CAD). The machining costs of the ROV came out totaling $825.00 (CAD), however, most of the work was donated by Dalhousie or done in house by company technicians.

In total including the administration costs of travel, registration, team logistics, and capital cost the total expense of the 2016-2017 season totaled $14762.15 (CAD). Accounting for potential sponsors the projected income of the Dalhousie Tigersharks totaled $12950.00 (CAD) thus giving an ending balance for the season of -$1762.15 (CAD). Therefore more sponsors were to be contacted for potential improvement in the operational budget.

Over the course of the design year, detailed costing was tracked over the production of the ROV prototype to gauge feasibility of the ROV in production. The costing report tracked the sponsors that were contacted and their potential donations. Of the other sponsors that were reached out too only a few were interested in funding the company's efforts, most notably those aforementioned above. The team also had previous savings form the older team total approximately $1100.00 and was put under Dalhousie Reimbursement. With the new savings and accounting for the surprise costs that appeared with manufacturing the ROV we finalize our budget. The detailed summary of budget is outlined in Appendix D: Budget Summary and includes the income and expenses dedicated to the development of Hammerhead.

Safety

The Tigersharks are heavily invested in developing learning opportunities for it members. These include safety and proper technics for any task used in the ROV's development. During the initial phases of designing we came together as a group and complete a Job Safety Analysis (JSA) surrounding the tasks needed to manufacture Hammerhead. This analysis can be view in Appendix C: Job Safety Analysis.

Our company policy includes standard safety procedures for all stages of construction. It is mandatory to wear safety glasses whenever we were working on any portion of the ROV, wear closed toed shoes and when working with sharp objects we must wear gloves. As an example when using mechanical tools such as a drill safety procedures associated with the tool must be followed, this included safety glasses, secured drilling station and closed toed shoes. As for electrical construction procedures, soldering and electricity are two components that require strict safety guildlines. For example to ensure safety during soldering, safety glasses, ventilation and clutter free spaces were utilized.

The Hammerhead has several safety features. We designed the ROV such that accidental or careless actions would not injure ourselves or anyone interacting with the ROV. For example, there are shrouds around each of the thrusters, to prevent damaging equipment or injuring fingers. Electrically, we have configured our system in a way which prevents shorts from occurring within the enclosure, and sealed wires to ensure there is no exposed conductors which could harm a person, or energize the water around the ROV.

Design Rationale

A synopsis of ideas for future improvements to designs, processes, and practices is essential to any entrepreneurial organization. Our design philosophy is to have simple, creative and powerful concepts coupled with creating learning opportunities for our members. These are the focus of our development of the Hammerhead and will be shown throughout the different design elements of the ROV.

Waterproof Enclosure

The major design element in this year's ROV is the integration of the electronics enclosure and main chassis into a single component. Designing a single part to act as both the electronics housing and the primary structural framework of the robot, the mechanical complexity of the craft is greatly reduced and more importantly, the vehicle layout could be designed with all systems in consideration for an optimized overall configuration. This design approach also made sense in terms of the manufacturability of the ROV. Because the enclosure already had to be machined on a CNC router to ensure that the sealing surface was in accordance with necessary specifications, it required no additional setup to then machine the mounting features for the thruster's directly into the enclosure. Machining the enclosure in this way also ensured that thruster alignment was accurate to a high level of precision. Figure 3 shows the integrated enclosure and thruster mounts which is crucial in ensuring that the robot's lateral thrust is properly balanced and that the ROV's position adjustment capabilities can be fine-tuned accordingly.

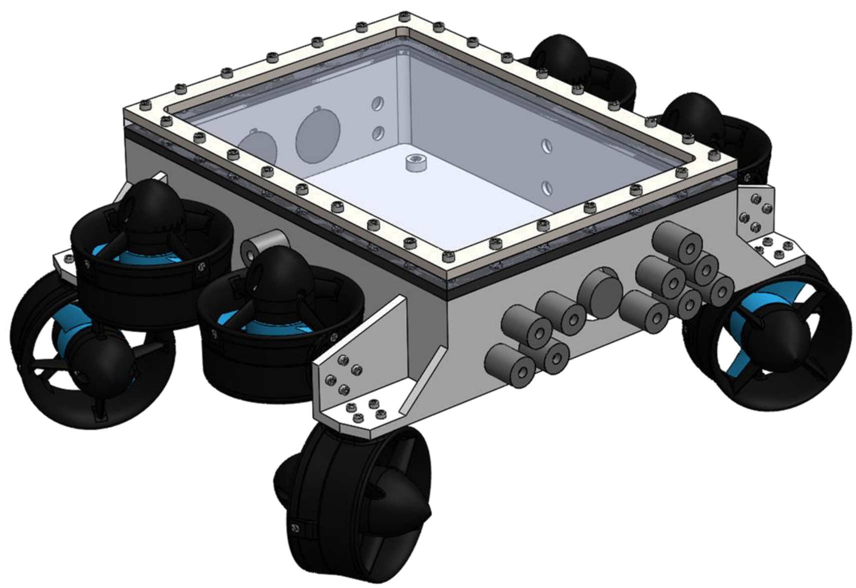


Figure 3- Waterproof enclosure with thrusters

The enclosure is made from UMHW and was chosen because it is a strong, flexible and easy to machine. The enclosure is sealed by a single rubber gasket that interfaces with an acrylic lid. To ensure that the enclosure will be waterproof up to the mission's water depth, a special adapter was made to fit into one of the enclosure's connector ports. This adapter allows the team to pull a vacuum of up to 14 psi (or to apply a positive pressure up to 40 psi) on the enclosure. Verifying that the enclosure will maintain sealing at these pressures before putting the ROV in the water is an important preventative measure to protect the on-board electronics.

Underwater Penetrations

In addition to a custom enclosure and gasket, the ROV incorporates custom electronics connectors that plug into the enclosure's outer wall and maintain a watertight seal. This penetration design uses a 3-position ¼" AUX plug potted into a plastic connector with a double O-ring seal. By choosing to use custom penetrations rather than one of many commercial alternatives, the cost of underwater connectors on the ROV was dramatically reduced and it was feasible for the team to have several spare sets of connectors on-hand in the event of a failure.

Thruster Layout

This year, eight thrusters are used to propel the ROV. Four lateral thrusters mounted in the configuration shown by figure 4 below enables forward, backward, rotational and strafing motions while four vertical thrusters provide the ascent, descent, pitch and roll motions. Mounting the lateral thrusters at a 45˚ angle to each other as shown below was found to offer favorable mobility in comparison to the 90 ˚ setup used in previous years as it gives much higher thrust in the forward/backward directions and lower thrust toward the sides. This thrust balance was chosen over the unbiased 45 ˚ layout because the ROV generally needs to move forward rapidly when traveling between mission sites, but needs slow, precise movement when strafing as this is motion is usually reserved for aligning the craft for prop manipulation. As previously discussed, design of thruster layout was heavily impacted by that of the electronics enclosure and in the final design these two systems became integrated into a single component to best facilitate both the thrust and electronics requirements.

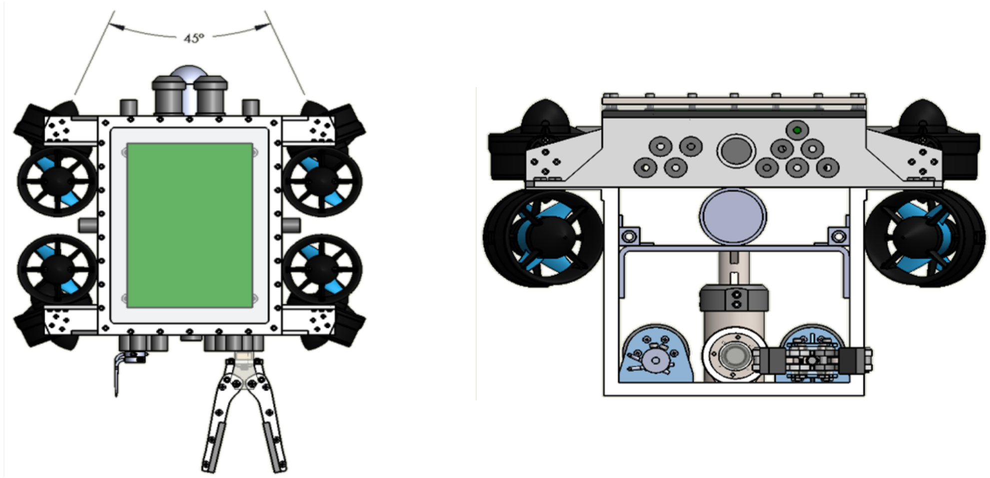


Figure 4- Thruster configuration of both vertical and lateral directions

Payload Tools

The Gripper

The ROV employs 3 primary payload tools that enable it to manipulate objects, collect samples and complete the set mission tasks as efficiently as possible. The primary tool used by the robot is the simple gripper shown in figure 5 below. This tool was designed to serve as a versatile manipulator with a design focus being put on ensuring a wide grasping area, high gripping strength and rapid closure time. These areas of focus drove the design away from several parallel-

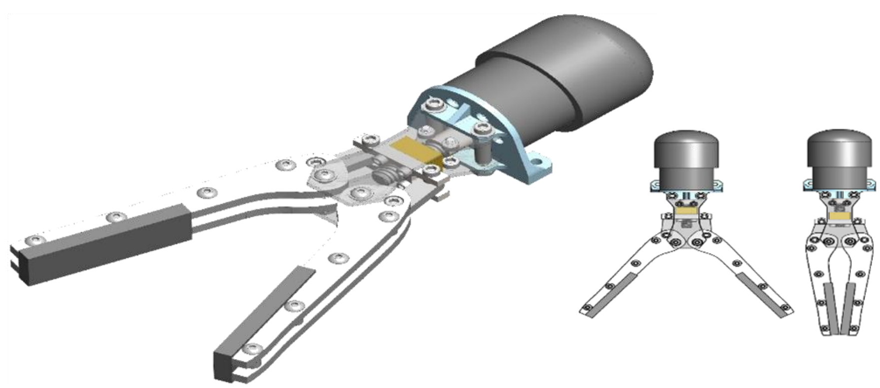


Figure 5 - Multi-purpose gripers displaying maximum opening

gripping mechanisms that were originally considered because, while they offered an improved grip on certain objects, they would not allow the claw to open very wide and would therefore increase the piloting challenge associated with grasping objects. Another advantage offered by the chosen design over a parallel-gripping linkage is the reduced complexity and size. The use of an ACME threaded rod to drive the gripping linkage means that the claw has a high-strength grip and that the claw will maintain a secure grip even after the motor has been shut off.

To further reduce size and complexity, the gripper design is directly integrated with that of the waterproof housing of the claw's drive motor. By incorporating mounting features into the enclosure cover to attach to both the gripper assembly and ROV chassis, a minimum number of components could be used. In addition, as the cover was to be 3D printed rather than machined, the increased part complexity resulting from these features posed no significant increase in manufacturing challenge. This design also ensures that the opposing forces of the claw are translated directly into the chassis without risk of the motor twisting out of position or of the motor wires being strained.

The Rotation Tool

The second payload tool used by the ROV is much less versatile in comparison with the gripper. The rotation tool was designed for the specific purpose of opening and closing a gate valve as required in the fountain repair stage of the ROV's mission. One of the major challenges associated with equipping the ROV to turn this valve was the fact that several different styles of valve handles are available and the team could not be sure which would be used for the final mission. For this reason, the tool was designed to be easily adjustable so that a wide range of valve styles could be accommodated by only minor adjustments to the tool settings. The final design as shown in figure 6 uses two prongs that can be inserted into the valve handle and spun by the enclosed tool motor. These prongs are mounted to the motor shaft in a way that allows their position to be adjusted both radially and circumferentially with respect to each other to achieve the desired prong spacing. Once the prongs are properly spaced, the adjustment screws can be tightened to lock the prongs in place.

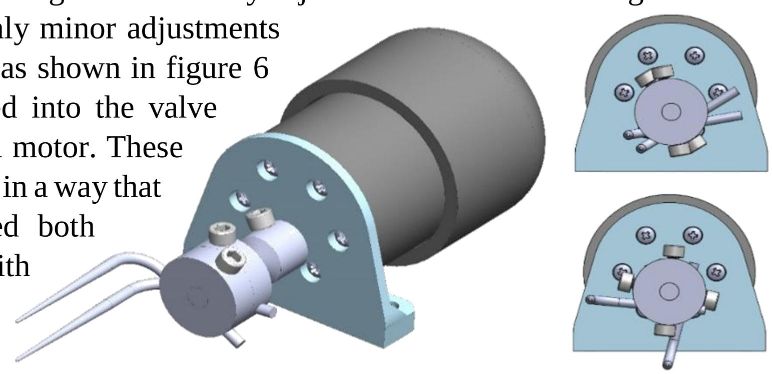


Figure 6- Rotational tool used to open gate valve

Motor Enclosures

To control the active payload tools on the ROV, brushed DC gear motors are used. These motors must be properly housed in a waterproof enclosure to ensure that they operate as efficiently as possible. Custom enclosures were designed for these motors that provide a simple and effective way to isolate the motors from the surrounding water while also ensuring that the team can easily access these motors for troubleshooting and maintenance purposes if needed. Shown in the exploded view in figure 7 is the motor enclosure design. The primary element of this enclosure is the removable lid which incorporates three different sealing mechanisms and eight separate rubber seals. This part was made on a high-resolution 3D printer to ensure that the various sealing surfaces would be built to their necessary tolerances and to reduce component cost. By incorporating all the mechanically demanding features of this design into the lid, it allowed the body and rear of the enclosure to be made from much more accessible materials. The body and backing of the enclosure are made from a length 1-1/2" ABS pipe and pipe cap. The wires are channeled through a hole in the back of the motor enclosure and are potted into the pipe cap. It also contains removable connectors that sit inside the enclosure allow the motor to be separated from these fixed leads and reserved as necessary.

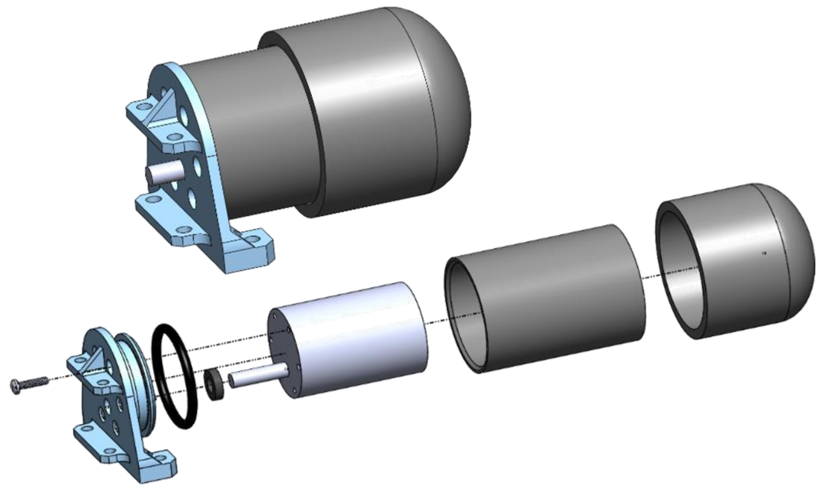


Figure 7- Assembled and exploded view of waterproof motor enclosures

Cameras

To ensure that the pilot's visibility was not limiting his ability to properly navigate the underwater environment and complete the mission at hand, the ROV is equipped with three onboard cameras. These cameras offer multiple perspectives for the pilot to use in navigation and have been mounted to best suit the ROV's tool configuration. Two different types of cameras are used on the ROV this year: a high-resolution (960H) Delta Vision underwater camera and two lower resolution board cameras that have been housed in custom waterproof enclosures shown in figure 8. Using these enclosed board cameras offers the advantage of lower weight and cost over the Delta Vision. Keeping camera weight to a minimum where possible was an important criterion for craft modularity as it allowed the locations of these cameras to be modified as required without having to reconfigure the robot's pre-calibrated buoyancy and ballast weights.

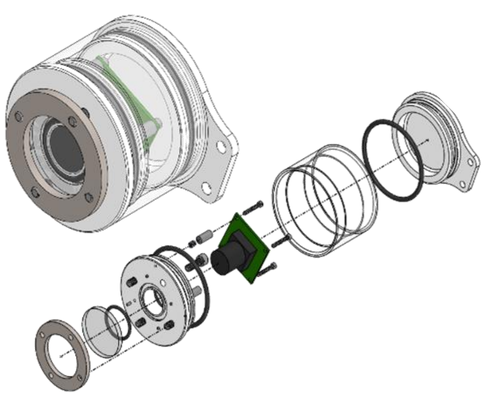


Figure 8 - Assembled and exploded view of board camera

Agar Sampler

The last of the primary payload tools on the ROV enables the robot to extract a 150mL sample of agar as required in the environmental cleanup mission task. As with the design of the other tools, a primary focus was put on reducing complexity and maximizing the reliability of the sampler. Following several preliminary tool designs, including auger and syringe-style extraction devices, a much simpler solution was identified as shown in figure 9 below. This tool design uses a thin-walled aluminum cylinder closed off at one end where a backflow-prevention valve is mounted. When the cylinder is pushed into the agar by the ROV, water in the cylinder is expelled through the valve and the cylinder gets filled with agar. When pulled back out, the one-way valve prevents the water from re-entering the cylinder and the agar remains in the sample extractor for the remainder of the mission. Using a simple, passive tool to accomplish this tasks allows for a reduction in the ROV's weight and complexity without compromising its ability to take samples effectively.

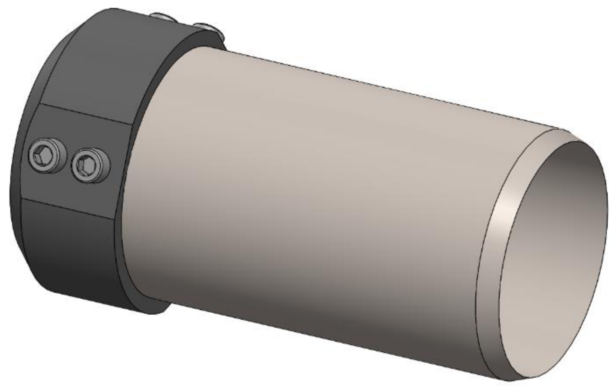


Figure 9- Agar Sampler Render

Controls and Electrical

To undertake the design of the electronics system, a rough System Integration Diagram (SID) like the one shown in Appendix A: System Interconnection Diagram was constructed. The primary reason for using this type of diagram is to greatly simplify the design process which leads to a faster development cycle and a more reliable system. The SID breaks the system into components and allows our engineers to abstract many of the complexities involved in individual components away during the initial design phase. It also made division of tasks easier for each component because the task that could be given to a smaller team or individual. The division of tasks worked well with our task oriented and one on one learning opportunity philosophy. Almost all of the electrical components on the Hammerhead are new due to a waterproofing failure with the team's previous robot. The complete layout of electronic components in the enclosure are shown in figure 10.

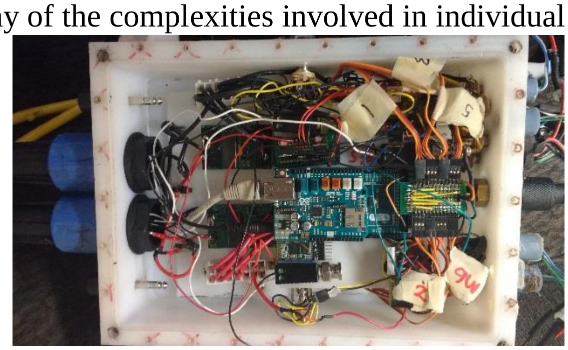


Figure 10- Internal electronic components

High Power:

The Hammerhead runs off of a 48VDC supply and has a maximum current of 21 A. This Voltage is converted to a number of lower voltages on board the Hammerhead to power the electronics and payload tools. The 48V is converted to 12V using two DC/DC converters inside the enclosure. This provides 1008W of power to the ROV and allows it to operate continuously under high thrust mode. The use of two DC/DC converts allowed for a number of benefits over other amounts of converters to provide this power. We used a decision matrix to help make our choice and is found in table 1. The benefits we looked at were cost, amount of wire connections and power available. We found that using two converters provided the greatest cost and space effectiveness compared to the other options. As the other options where too expensive and more wires also presented a point of failure which offset the gains from greater redundancy. Additionally this increased the integration time of the converters, making assembly more difficult and in the end made the decision to conserve space and create a tidy electronics system with only two convertors. Commercial converters were chosen over home build because of the difficulty in creating an efficient high power DC/DC converter.

# of DC/DC Converters	1	2	4
Cost	$517	$290	$290
# of Connections	5	10	20
Power	2000W	1008W	960W

Table 1- DC/DC decision matrix

To power miscellaneous systems on the Hammerhead, such as the Arduino, Bluetooth and the lasers a linear regulators providing 9V, 5V, and 3V DC was installed. Linear regulators were chosen because they were cheaper than switching power supplies and greater efficiency was not needed.

Data and Low Power:

The most important part of the on board control system of the Hammerhead is the Arduino Mega microcontroller. As shown on the SID in appendix A, all logic and control run through the Arduino. When choosing a microcontroller our priorities were to create the most reliable, simple and effective control system possible. To easily compare different controllers, our company created a selection matrix for three options shown in table 2 and ranked them, 1 being the best.

Microcontroller	Arduino	Raspberry Pi	PIC
Familiarity-Important	H	H	L
PWM-Very Important	H	L	L
Communication-Important	H	H	L
Cost-Important	L	M	H
Speed-Less Important	M	H	M
Rank	1	2	3

Table 2 - Microcontroller decision matrix

As shown, the Arduino represented a far superior choice to both the PIC and Raspberry Pi. To facilitate simple, effective communication between dry side and wet side systems, an Ethernet Shield was added to the Arduino. The reason for choosing Ethernet over other communication methods is discussed further in Software Rationale.

The camera system onboard the ROV is often the only sense that pilots are given and it is essential that they operate effectively and reliably. Our company has committed to implementing a camera system that worked without any noticeable latency and without visible distortion. Early in the Hammerhead's development we attempted to use a system that utilized analog cameras such as the Delta Vision camera shown in figure 11 with Video DVRs fed into the control laptop. We discovered that there was a half second of latency when testing this system and deeming this as unacceptable. Switching to a fully analog setup which fixed the latency issues. Details will be covered in more detail in Topside Electronics. Anticipating interference from the power wires in the tether, we purchased baluns from Northern. These baluns convert the camera signal into a differential pair that is sent up the tether and converted back into a single wire on the surface by another balun. Although this increases the number of wires in the tether we found that it greatly reduced the effects of interference.

Figure 11-Delta Vision camera

Tool Motor Control

The tool motor control is a simple H-bridge circuit. It was made in series with a relay circuit as seen in figure 12. Using the H-bridge and relay circuit together allowed for the use of two to three bi-directional tool motors with only one H-bridge and reduced the footprint inside the electronics box. The transistors used are 75321P NMOS, IRF5305 PMOS and BS170 NPN transistors. The NMOS and PMOS transistors were chosen because they were in-house transistors that were rated for 3A. The BS170 NPN was chosen because it was found in-house and was small in size. Since there is not a high current demand for the logic switching role they possess, it was a suitable transistor.

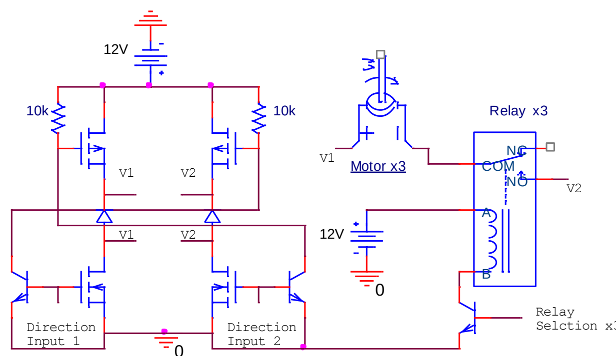


Figure 12 - Motor control circuit

During the operating of the Arduino two pins are used to direct the action. The first pin is the directional input, which determines the direction of motor rotation and the second is the relay selection, which determines which motor will be operated. There are 5 pins in total that are reserved for motor selection on the Arduino. This means there is an additional benefit to the circuit in that it reduces the number of reserved pins on the Arduino to operate the tools motors.

To control and drive the T100 and M100 Blue Robotics thrusters used for propulsion our company had the option of commercial or house made drivers. The team did design our own motor drivers but because driving 3-phase DC motors represented a notably more difficult task. The lack of optimizations available coupled with the low cost of commercial options the team decided to purchase 8 Afro ESCs from the company called HobbyKing.

The decision to use Afro ESCs to drive the Hammerhead's thrusters was primarily due to their compatibility and wide use with the Blue Robotics thrusters. While Blue Robotics also manufactured Afro ESCs, our company sourced the drivers from HobbyKing. While both ESCs performed effectively the same, HobbyKing's were half the cost and enabled us to purchase backup ESCs. The primary reason for the difference in cost between the ESCs was the presence of reversible thrust firmware on the Blue Robotics models. To overcome this, the team utilized the KKMulticopter Flashtool and an Arduino to flash Blue Robotics firmware onto the ESCs, thereby removing any differences between the models.

Bluetooth Connection

A HC-05 Bluetooth sensor was used for transmission of data from the contaminated container. This device is configured in slave to connect with the master transmitter. Once the two devices have connected, the Arduino uses software serial ports to interpret the message and send up the message. The function code is shown in figure 13.

```
void Bluetooth(){
SoftwareSerial Genotronex(10, 11); // RX, TX
char BluetoothData; // the data given from Computer
// put your setup code here, to run once:
Genotronex.begin(38400);
Serial.begin(38400);//Baud Rate to match HC-05
pinMode(10, INPUT_PULLUP);
pinMode(11, OUTPUT);
for(int i=0; i<10; i++){
Genotronex.listen();
if (Genotronex.available()>0){
BluetoothData=Genotronex.read();
Serial.println(BluetoothData);
} } }
```

Figure 13 - Sample Bluetooth function code

Testing revealed that the Bluetooth was able to send a signal that can travel up to 8cm in water. This is the case whether the receiver is inside a thin waterproofing material or inside the enclosure. With these finding the team decided that it was beneficial to not waterproof the device and its connections but to place the device inside the electrical enclosure.

Laser

The lasers are used to distance measurement and this is achieved by separating the two lasers by 11cm parallel to each other and a capturing the separation on a object through the camera . When the laser is shone on an object, the lasers will have an apparent distance apart from each other which correlates to a distance that is determined by us through testing. This testing is done by varying an object's distance from 10 cm to 350 cm and measuring the apparent separation on the monitor. These results are then graphed in excel and the equation used to interpret an object at any distance. The lasers used on the Hammerhead are 5mW, 650nm red lasers. The company decided to use the red lasers due to greater availability and because we found that the intensity of the 5mW red laser and 1mW green laser are the same at 3.5m away.

Tether

Serving as the only link to the surface from the robot, the tether is essential to an ROV's operation. We have put a great deal of thought into the tether and factored in important variables such as buoyancy, wires, wire gauge, and strength. The Hammerhead utilizes two 15m neutrally buoyant tethers from VideoRay shown in figure 14. Each tether contains four 18AWG wires for power and three twisted pairs for Ethernet and camera signals. The decision to use a commercial tether offered a greater number of benefits than using a house made tether. These benefits include neutral buoyancy, strength and cost. It also offered greater compatibility with the penetrations used on Hammerheads enclosure. Two tethers are used instead of one to decrease power losses over the tether, something which caused issues in our company's previous ROV. This also increase the number of camera signals and data lines that could be used in the electrical system.

Figure 14- Example of the neutrally buoyant tether

Topside Electronics

Traditionally, ROVs have had bulky topside control systems which increase deployment time and reduce the overall user experience. The importance of this is shown by the success of ROV companies such as VideoRay that have cut down on these shortcomings. Recognizing this, our company has created a compact and easy to use topside electronics system which consists of two key parts: the Camera Display System and the ROV Control Interface.

The Camera Display System consists of just three main component groups: baluns, a multiplexer, and a monitor. Utilizing these three parts, the Hammerhead offers a lightweight, simple, and easy to use visual display. The use of a multiplexer is justified in that it allows users to view more than one camera at a time. Furthermore it contains additional features, like picture-in-picture mode that is especially valuable for utilizing payload tools, and freeze-frame, allowing environments to be analyzed without needing to keep the Hammerhead steady.

Hammerhead's ROV Control Interface is also lightweight, simple, and easy to use. The system consisting of just two components, a laptop and a controller. The new system was created by lessons learned from our company's previous control system. One main problem we quickly identified with the old system was number of different connections between the controller and the ROV. This problem was overcome by removing unnecessary parts, such as the router, we were able to simplify both operation and setup of the control system. A single program is automatically run on startup and to enable pilot control of the Hammerhead, a single binary file is run. This means pilots can be trained to use the Hammerhead's system far more quickly. One additional feature of these control systems is that the ROV control interface fits entirely within the Camera Display System, making storage and travel easy.

Software

Developing the software for the Hammerhead focused on a number of key points: responsiveness, reliability, simplicity, and control. Honing in on these areas we significantly improve the control and handling of the Hammerhead. Despite the overall simplicity of Hammerhead's software, it offers a number of features which set it apart, such as active stability and scaling thruster control.

As outlined in Appendix B: Software Flow Diagram, the Hammerhead's software is divided into two main sections: topside code programed on the ROV Control Interface, and microcontroller code programed on the Hammerhead's on board Arduino. Both codes are written in the program language of C. C was used because it was fast, simple, and familiar to the Hammerhead's software team. An added benefit is it paired well with Linux's Application Programming Interface that was chosen because of its ease of use and wealth of features. A key feature of the structure of the topside code is that it uses asynchronous reading of the controller, keyboard, and of messages from the ROV. This means for example, messages from the ROV are only processed once, aiding in the responsiveness of the code. Both sets of code are extremely terse, making them more reliable and easy to read, being implemented in under 1000 lines total. As previously mentioned, the Hammerhead has scaling controls that begin at 50%. This means a greater sensitivity in Hammerhead's controls, allowing the Hammerhead to utilize a high thrust mode to quickly move between objectives, and a lower thrust mode to delicately complete objectives.

For communication between topside and the Hammerhead's Arduino, a number of different standards were considered. Among them were Ethernet via the User Datagram Protocol (UDP), Ethernet via the Transmission Control Protocol (TCP), and RS232 Serial. RS232 was the first to be discarded, as compared to the two Ethernet methods, RS232 offered little in built in error checking (occupied by UDP and TCP) and had inferior signal propagation. Furthermore, code to transmit serial was more complicated. Next, TCP and UDP were compared, with TCP offering error correction and preserving packet order and UDP offering far lower latency. UDP was chosen for the Hammerhead because packets could be easily constructed in such a way so that packet order did not matter. Additionally, due to the nature of ROV communication being quick and nearly constant, error correction was not needed, thereby eliminating TCP's other benefit. This allows the Hammerhead to utilize the lower latency of UDP to its fullest, offering quick, responsive controls.

Active Stability

Utilizing the ADXL335 accelerometer and its four vertical thrusters Hammerhead can identify and correct any undesired rotation. This active stability allows the ROV to lift larger loads with more control and less effort for the pilot. Active stability sacrifices some maximum thrust and uses electricity unlike a traditional passive stability system that uses ballast and buoyancy to create a tendency for the craft to stay upright. With Hammerhead's excess of thrust and electricity the active stability system is superior because it allows for reduced mass and drag as well as the ability to hold angles other than upright.

The ADXL335 provides the 3-axis acceleration information required to determine Hammerhead's orientation. Using acceleration do to gravity as a reference, pitch and roll can be calculated. The equations are as follows:

$$pitch = \arctan \frac{a_y}{\sqrt{a_x{}^2 + a_z{}^2}} \qquad roll = \arctan \frac{-a_x}{a_z}$$

These values can be further improved by using cached values from the previous pitch and roll to smooth out any sudden changes that are not representative of the ROV's true orientation. With pitch and roll of the ROV found using the four vertical thrusters at each corner of Hammerhead, it can be used to rotate the ROV to the desired orientation. For example, fore thrusters can push the front up while aft thrusters push the rear down resulting in the ROV pitching up.

There were several challenges to overcome when implementing the active stability system on Hammerhead. Latency in calculating pitch and roll then applying any thruster values is a huge concern. If the active stability system is too slow the ROV could fail to correct orientation before the ROV losses control or worse an aggressive and late correction could further reduce the ROVs stability. Calculating and applying any corrective thrusts every 10 milliseconds ensures latency is not an issue. Optimal placement of the vertical thrusters to provide leverage when correcting pitch and roll reduces energy required. Also a firm mounting of the accelerometer ensures that sensor values represent acceleration of all Hammerhead's mass. Overcoming these challenges has led to an innovative way to reduce mass and increase carrying capacity.

Critical Analysis

Testing and Lessons Learned

At Dalhousie Tigersharks we use both our engineering design skills and thorough testing methodology throughout the development of the Hammerhead. This allowed us to supplement our knowledge with concrete proof of concept for our ideas and enable a good learning experience during our build process.

In both the electrical and software systems, a component testing system was constructed in which each part of the Hammerhead's electrical and software systems were tested individually. A partial integration test was performed, allowing for the interaction between components to be tested without the additional complexity of a full integration test. After these partial tests, a full scale integration test was done to ensuring proper operation of the Hammerhead. One key example of component level testing was testing the DC:DC converters. In previous years, DC:DC converters were a common failure point, with numerous component level and integration problems arising. This year due to the new testing procedures, the DC:DC converters were thoroughly tested beforehand and any integration issues were quickly corrected. An example of partial integration testing was the interaction of the motor drivers and the Arduino. The Arduino was used to apply voltages to the motor driver which allowed for the software, motor driver, and the link between the two to be tested. This avoided an issue experienced in our company's previous ROV in which motor drivers were destroyed due to incorrect wiring. The success of this test procedure is clearly shown in the final integration of the electrical and software systems. All electrical components were brought together in a single build session without any major issues. Considering the scope of this project, this is a major feat.

Members of Dalhousie Tigersharks also utilized more specific tests when engineering knowledge and experience was lacking. For example, none of the members of the team were familiar with the propagation of Bluetooth through water. This is an example of a learning opportunity as we needed to test the propagation of our Bluetooth module. The problem presented a challenge in a key design decision: if the Bluetooth module used could not communicate far enough through water we would need additional penetrations in the enclosure and the creation of a separate Bluetooth enclosure. The team conducted a series of tests to determine the distance of communication in a local pool both inside and out of the enclosure. Unexpectedly the team found the propagation to be better than expected: 8 cm vs 3 cm predicted. Using these learning opportunities, the team was able to extend their knowledge of systems and make the Hammerhead a simpler and more reliable vehicle.

Challenges

Despite the success of this project, our company has faced a number of challenges getting to this point. The largest one that we faced was construction at our university, beginning of the destruction of the building that contained our old shop. Over the course of the project, this caused other setbacks, including manufacturing delays at Dalhousie's machine shop and an inability to find staff members. The Tigersharks were able to overcome many of these challenges through scheduling, hard work, and taking a proactive approach to this project.

Some technical challenge that we faced was the layout of the electrical system and designing for light and electromagnetic functions such as the laser and Bluetooth on-board the Hammerhead. Due to the low amount space caused by plastic sourcing cost, there was significantly less space than expected. To overcome this, the team both modeled and discussed how to manipulate the location of the electronics inside of the enclosure using sheets of paper and component measurements. We then chose parts with smaller footprint. An example of this is the motor drivers, which were designed by the team to reduce their footprint.

Some mechanical challenges were limitations of the material and shop time. For example, drilling the penetrations for the connectors was delayed due to the construction. Communication was crucial in getting the penetrations drilled and the team took steps to increases the contact with the shop hands. This gave a need to understand what resources are at our disposal when making design decisions and have better communication with our suppliers.

Over all we overcame our challenges without jeopardising the goal of this project to entering the MATE competition. This was a great achievement for the company and shows how teamwork and perseverance can accomplish our goals.

Future improvements

Our company is always looking to innovate and learn from our past mistakes. The challenges and testing we have done have given us valuable knowledge and push us to create better systems. In the future, there are several regions of both the mechanical and electrical system that we would like to improve. Such as printed circuit boards, connectors and motor enclosures.

Next year we would like to manufacture printed circuit boards to simplify the mounting and wiring needed inside the enclosure. Ideally, we would have two PCBs in the ROV. One would be used for higher voltage/current power conversion and distribution, while the other would be used for lower power components such as sensors.

We would also like to improve data access to the enclosed processor without opening and dissembling the enclosure. To do this, we want to design and incorporate a waterproofed port which we could connect a USB cable to. Within the enclosure, this port would connect directly to the Arduino, allowing us access to program without any disassembly.

One of the main areas that needs improvement is the connector plugs for the thrusters and tools. The current design is a 1/8" plug which is potted into a 3D printed connector with two O-ring grooves and a hole for wires to exit at the opposite end. With the current 3D printed connector, it is difficult to prevent the epoxy from leaking during the potting process. Furthermore, the 1/8" plug sometimes sets at an angle when the epoxy dries, which means that it cannot be plugged into the 1/8" port. The 3D printed connector should be redesigned to fix these issues.

Currently, the payload tools all used brushed DC motors. For long-term motor use each motor needs to have its own waterproof enclosure. Developing effective motor enclosures was difficult and time-consuming this year, so future designs should consider using brushless DC motors to avoid the need for waterproofing.

Our team has many ideas and designs to improve the Hammerhead but are very pleased with the outcome of this year's ROV. Figure 15 is a full render of the Hammerhead and its payload tools we will use in competition. We will strive to compete to the best of our abilities and learn from any challenges we might face in this year's competition.

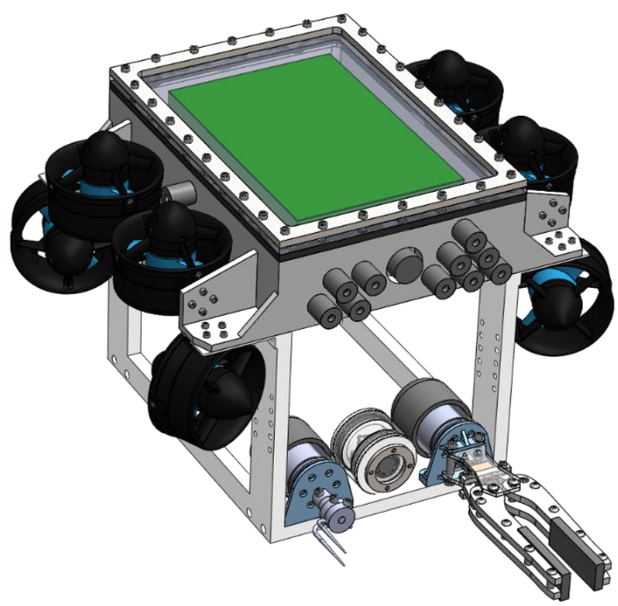
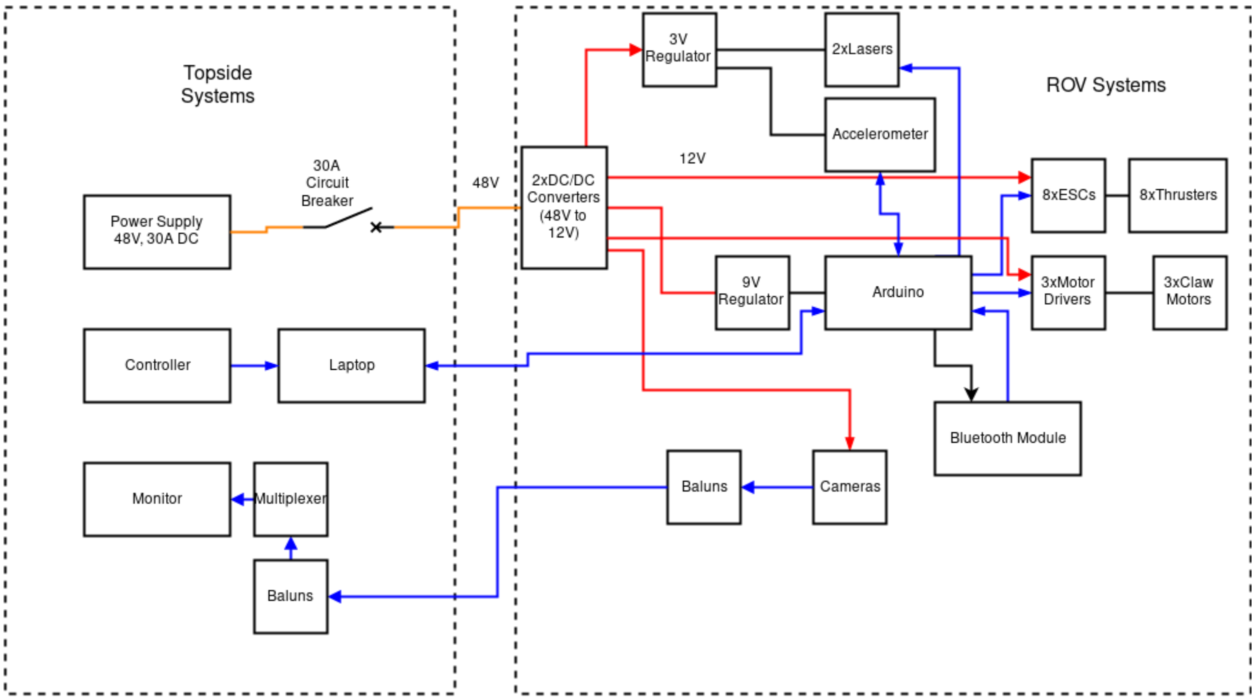


Figure 15- Full render of the Hammerhead

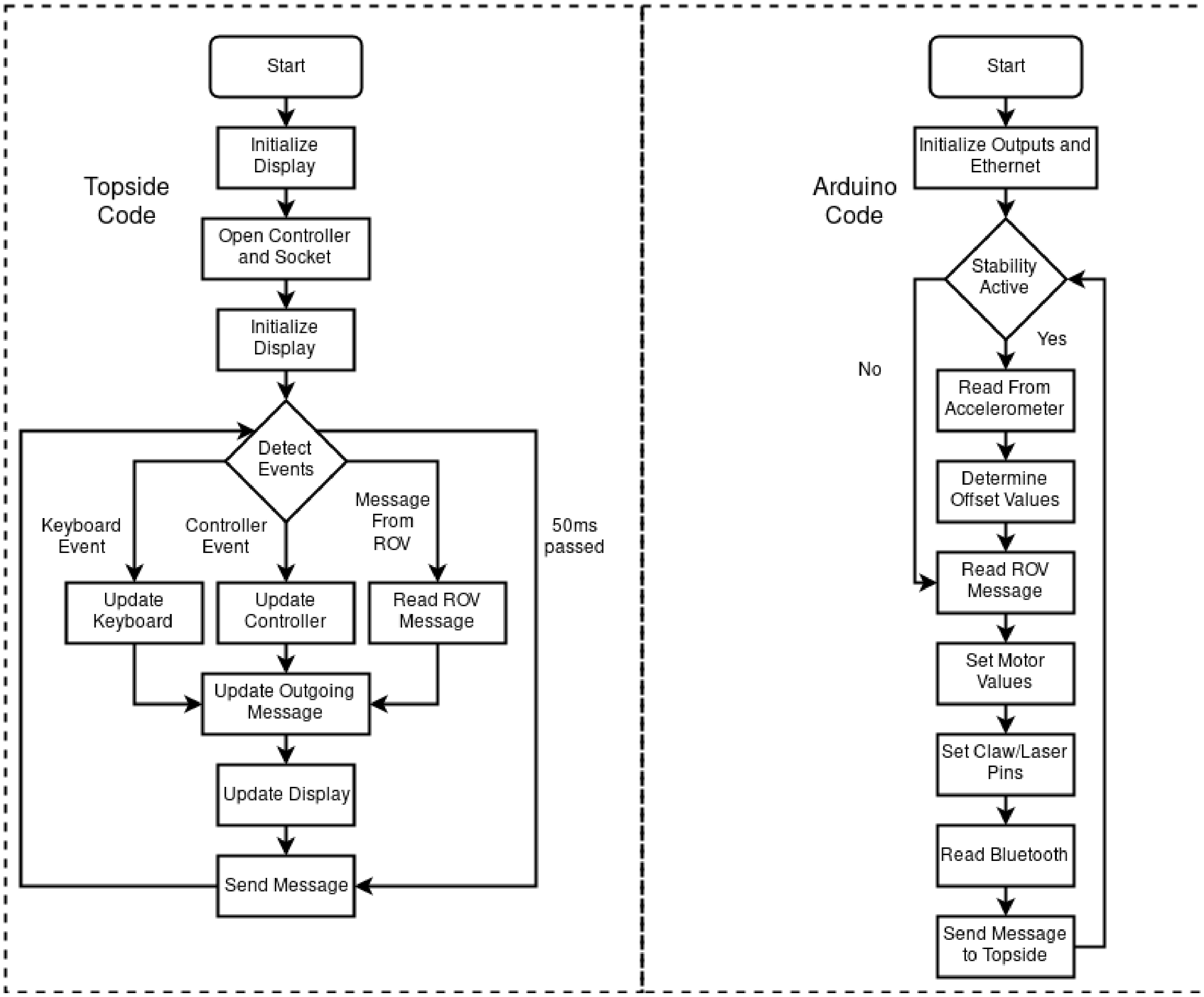
Appendix A: System Interconnection Diagram



Legend
12V Power
Data
48V Power
Misc Power

Breaker Power Calculations	
Thrusters	900W
Laser	0.005W
Sensors	0.1W
Arduino	0.225W
Tool Motors	58W
Total	958W
Total/0.95 DC/DC Eff	1008W
Power / Voltage	21A
Current * 1.5	31.5A = 30A Breaker

Appendix B: Software Flow Diagram



Appendix C: Job Safety Analysis

TASK	HAZARDS	PREVENTIVE MEASURES
1. Workstation Organization	-Cluttered work station -Chemical hazards -Hazardous tool use	-Make sure the workstation is well organized before starting anything. -Ensure chemicals are in proper containers and that any spills are properly cleaned up. -Ensure proper tool use and handling
2. Transportation/Handling	-Slipping/Tripping/Falling -Physical Strain	-Ensuring proper footwear is worn. -Make sure the tether is wrapped up and organized. -Ensure proper lifting technique is used when handling ROV. -Ensure that more than one person is lifting the heavy loads.
3. Pre-Launch Setup	-Improper electrical connections -Tripping hazards	-Ensuring proper seal of electrical components -Ensuring proper connection of electrical connections -Ensure tether is properly laid out when unraveling.
4. Launch	-Improper safety barriers around pool -Tripping hazard -Open water/drowning hazard -Physical strain	-More one person take part in launching ROV into water. One person to launch ROV into water with another person restraining launcher from falling into water. -Ensure tether is flat on floor when unravelling from tether coil. -Ensure persons who cannot swim are to wear life preserver vest to prevent drowning. -Ensure proper lifting and moving when handling ROV. Use more than one person if needed.
5. Flight	-Tether tripping hazard -Open water hazard	-Ensure tether is unraveling in a controlled manner to prevent tripping -Ensure persons are clear of the pool side to prevent from falling into water.
6. Recovery and Teardown	-Tether tripping hazard -Falling hazard -Strain hazard -Electrocution hazard	-One person to pull tether up with ROV with a second person travelling the tether in a safe and organized manner. -More than one person take part in recovering ROV from water. One or persons to recover ROV from water with (an) other person(s) restraining receiver(s) from falling into water. -Ensure proper lifting technique is used when handling ROV. -Ensure all power is turned before removing/handling any electrical connections.
Required Training: -Proper lifting technique to be taught to all persons handling ROV. -Proper use of tools and chemicals used in construction and maintenance of ROV prior to launch.		Required Personal Protective Equipment (PPE): -Life preservers for those requesting -Proper non-slip work shoes to be worn

Appendix D: Budget Summary

Summary			
Income	$14,955.00		
Expenses	$14,772.16		
Ending balance	$182.84		
Income		**Expenses**	
Sponsorships	$4,930.00	**Robot Expenditures**	$3,136.63
Dalhousie Reimbursement	$10,025.00	Waterproofing	$434.00
Potential Sponsors	N/A	Tools	$5.00
		Chassis	$0.00
		Machining	$825.00
		Electrical Parts	$1,511.04
		Motors	$322.64
		Sensors	$38.95
		Administration Expenditures	$11,635.53
		Transportation	$10,800.00
		Logistics	$835.53

Appendix E: Acknowledgments

Dalhousie Tigersharks would like to formally thank the following individuals and organizations for their enduring support. Our platinum tier sponsors are Shell Canada, and Dalhousie University who donated the capital cost for the ROV. Our silver tier sponsors are Engineers Nova Scotia that sponsored our registration fees. Our bronze tier sponsors, Jentronics Inc., Aquatron Laboratory, and Survival Systems who donated parts, services and continuing support.

We would like to give a big thank you to the MATE Center for organizing and pushing teams to compete in a friendly and fun learning environment. Below are our wonderful sponsor's logos, thank you for all your support!