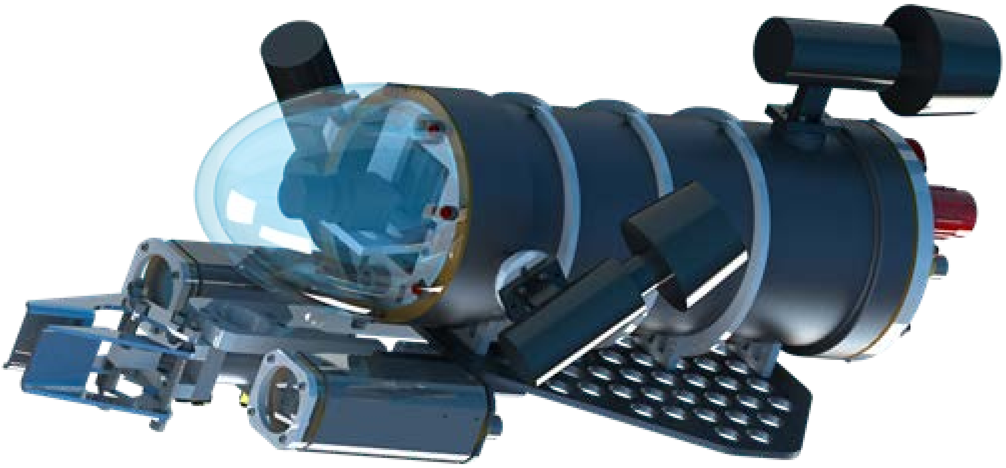
Robotic Aquovations

Ohio State University, Columbus, Ohio, U.S.



TECHNICAL REPORT

2015 MATE International Competition EXPLORER Class

Team Members:

Achal Singhal – CEO
Sara Mahaffey - Vice President
Andrew Lee - CFO
Kyle Berry – Team Leader: Mechanical
Conor Cary – Team Leader: Electrical
Marshall Sayre - Senior Mechanical Engineer
Charles Fletcher – Senior Electrical Engineer
Elizabeth Clapp - Design Engineer
Erika Klek - Design Engineer
Lisa D’lima - Process Engineer
Marissa Andrews - Process Engineer
Peter Edin - Design Engineer
Tanner Strickland - Process Engineer
Sam McTurner - Process Engineer
Amber Dock - Process Engineer
Mark Schreck – Design Engineer

Abstract

The Ohio State Underwater Robotics Team spent this year designing and constructing a Remotely Operated Vehicle for competition at this year's MATE International ROV Competition. Jaws-2 is the "sequel" to last year's Jaws ROV which did not make it to competition. Jaws-2 has been rebuilt from the ground up using entirely new hardware and software to make sure that it is a strong contender for the competition. Working with limited resources and an all new project proved difficult to handle but we were up to the task and rose to the challenge.

Jaws-2 is designed to conduct repair operations, relay information to the surface, and make predictions on iceberg movements that could pose a hazard to offshore drilling sites. The OSU UWRT consists of a small number of specialized engineering undergraduates with majors ranging from Electrical and Mechanical Engineering to Welding and Chemical Engineering. The design, construction, and testing of Jaws-2 was a learning experience which will be invaluable for use at next year's competition and the design lessons learned will streamline the process for the 2016 MATE International ROV Competition.

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1. Project Management

Robotic Aquovations is a company that truly wishes to make a mark on the ROV industry and is able to produce cutting-edge, resilient, and quality products. At the heart of the company is a management system that allows the company to function in a productive and time efficient manner. The management system relies on cooperation and communication between the two departments (Mechanical, Electrical and Software) within the firm. An organizational chart can be found below (Figure 1), which illustrates the structure of the company.

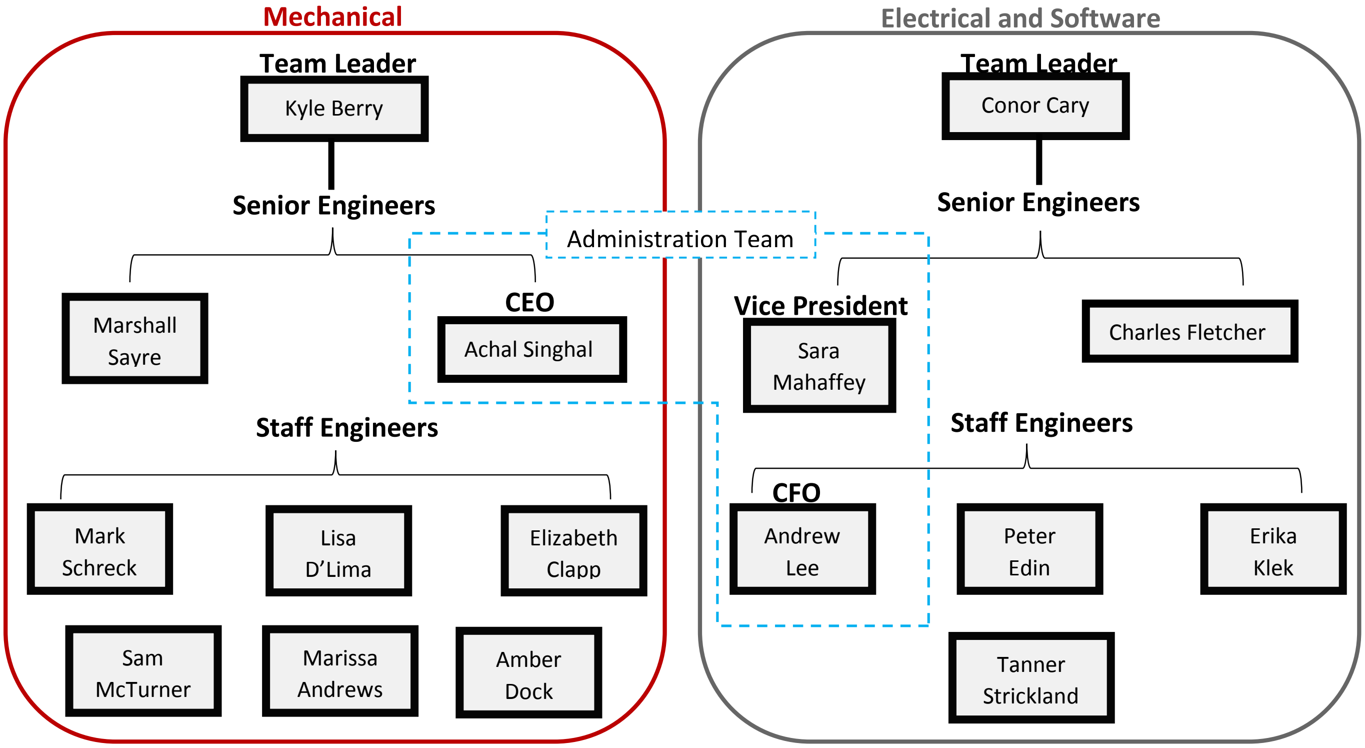

Figure 1: Robotic Aquovations' Organizational Chart.

The administration team is comprised of engineers within the company who represent both the Mechanical and Electrical and Software Departments. The integration of these key roles within the engineering teams and across departments is fundamental for maintaining communication and ensuring that company needs are being met. The team leaders direct and organize each department and work closely with the senior and staff engineers to complete the company's various product requirements. The senior engineers are experienced members of the company and are extremely familiar with the current and past ROVs and are therefore equipped to provide staff engineers with technical support. The staff engineers assist with the design, testing, and manufacturing of the ROV and its secondary components.

The organization of a company can be very challenging and demands more than just a hard-working staff. In order to maintain the schedule that is required to keep the project on-track, the company has created a Gantt chart (Figure 2, next page) that was closely followed during the duration of the project. The Gantt chart divides the project tasks into mechanical, electrical, software, payloads, and testing.

WBS	Task	Start	End	Work Days
1	**Mechanical**			
1.1	Preliminary Design	Mon 9/01/14	Thu 9/25/14	25
1.2	Team Review	Fri 9/26/14	Mon 9/29/14	4
1.3	Final Design	Tue 9/30/14	Tue 10/07/14	8
1.4	Create Manufacturing Drawings	Tue 10/07/14	Wed 10/22/14	16
1.5	Manufacture Components	Thu 10/23/14	Thu 1/15/15	85
1.6	Assembly	Fri 1/16/15	Thu 1/22/15	7
2	**Electrical**			
2.1	Initial Electrical Schematic	Mon 9/01/14	Tue 9/30/14	30
2.2	Electrical Component Evaluation	Wed 10/01/14	Tue 10/21/14	21
2.3	Team Review	Wed 10/22/14	Thu 10/23/14	2
2.4	Final Schematic	Fri 10/24/14	Thu 11/13/14	21
2.5	System Integration	Fri 1/23/15	Sat 2/21/15	30
2.6	Topside Control Station	Mon 3/23/15	Tue 4/21/15	30
3	**Software**			
3.1	Learn ROS	Mon 9/01/14	Thu 10/30/14	60
3.2	Create Node Diagram	Fri 10/31/14	Sat 11/29/14	30
3.3	Create Flowcharts	Sun 11/30/14	Fri 12/19/14	20
3.4	Joystick node	Sat 12/20/14	Sun 1/18/15	30
3.5	Control Node	Thu 12/25/14	Tue 1/13/15	20
3.6	Stabilization Node	Wed 1/14/15	Mon 2/02/15	20
3.7	Camera Node	Tue 2/03/15	Tue 2/03/15	1
4	**Payloads**			
4.1	Manipulator	Thu 2/05/15	Fri 3/20/15	44
4.2	Task-specific Payload Design	Sat 3/21/15	Sun 4/19/15	30
4.3	Manufacture Payloads	Mon 4/20/15	Tue 5/19/15	30
5	**Testing**			
5.1	Housing Watertight Testing	Sat 1/17/15	Fri 1/23/15	7
5.2	Individual Electrical Component Testing	Sat 2/07/15	Sat 2/28/15	22
5.3	Software Testing - Individual Nodes	Sun 3/01/15	Sat 3/14/15	14
5.4	Full Electrical System Testing	Sun 3/15/15	Sat 3/21/15	7
5.5	System Integration - Full ROV Test	Sun 3/22/15	Sat 3/28/15	7
5.6	Control System Calibration	Sun 3/29/15	Sat 4/11/15	14
5.7	Camera System Testing	Sun 3/29/15	Sat 4/04/15	7
5.8	Regional Competition Pool Testing	Sun 4/12/15	Sat 4/25/15	14
5.9	MATE Competition Pool Testing	Sun 4/26/15	Sun 6/21/15	57

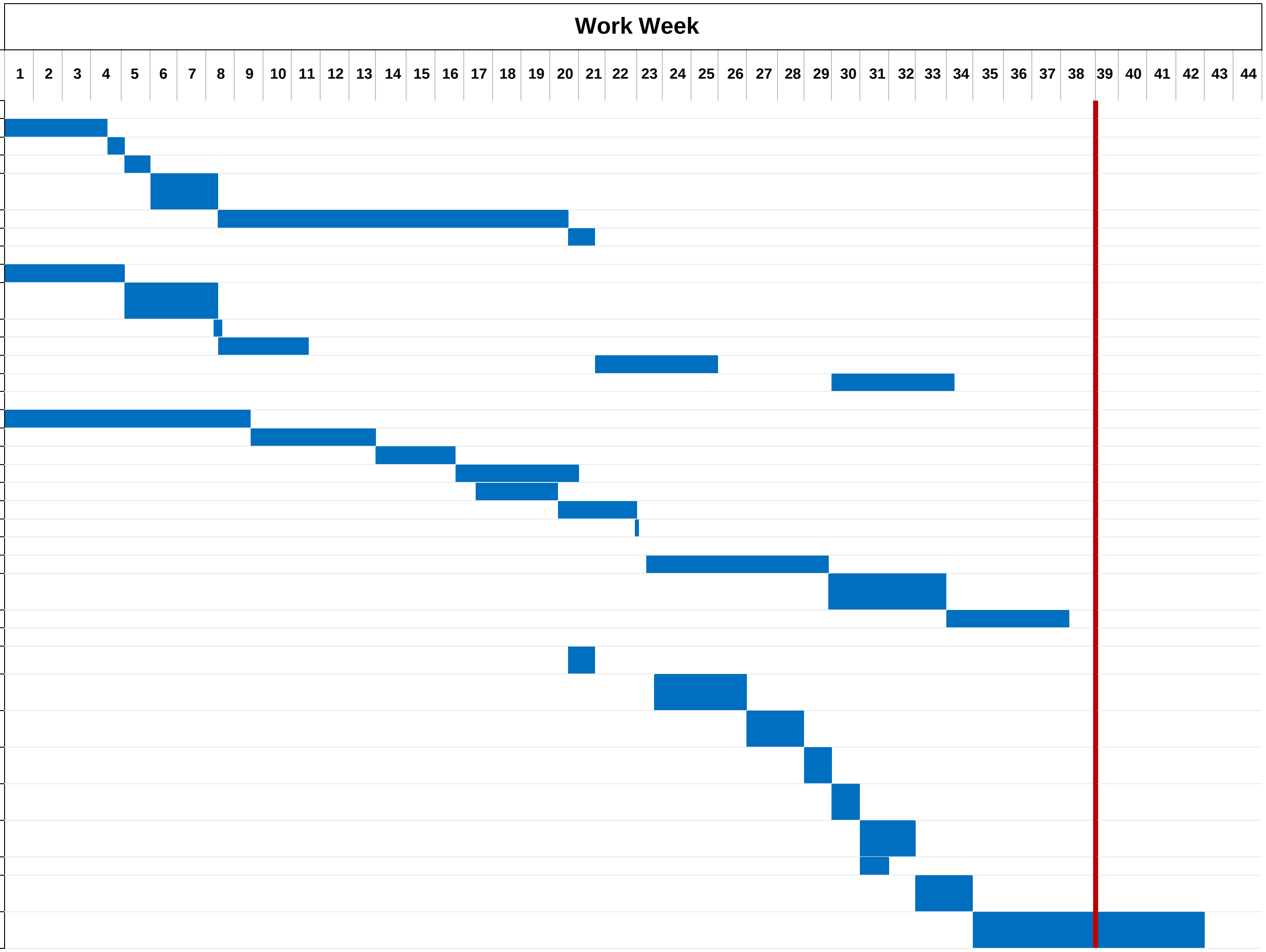

Figure 2: Gantt Chart.

2. Finances

The budget for the company was spilt up in to 7 categories as seen in Figure 3 below. The total expected cost was $30,000. The projected cost for each section was based on the costs of previous years' projects.

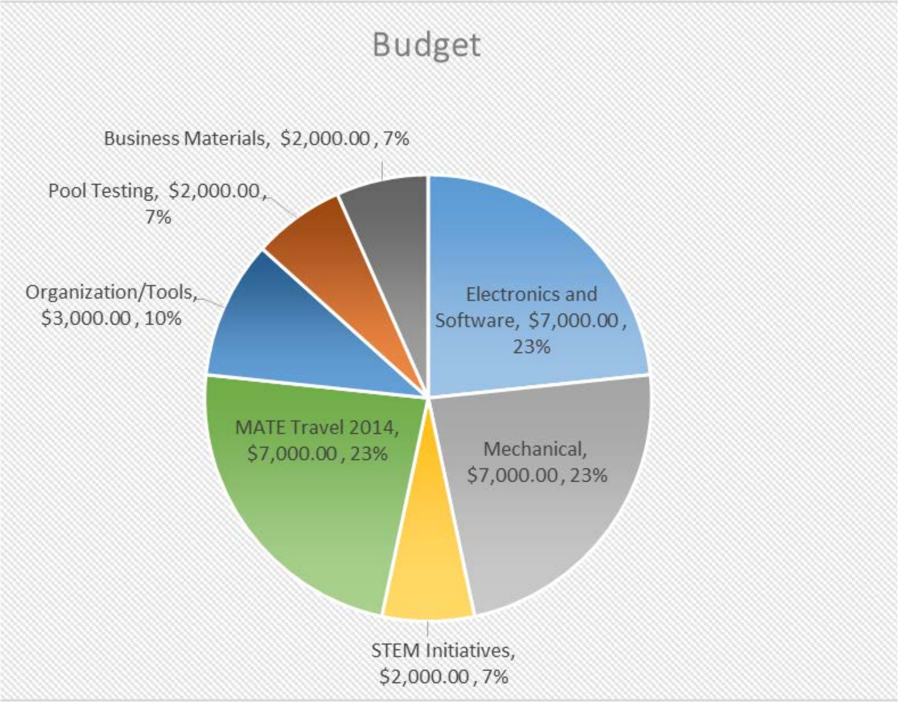

Figure 3: Budget Pie Chart

A summary of the funding provided to the company can be found in Table 1 below. The budget was set well below the total income to ensure that adequate funding was available in case of an issue during the year and to have reserve funds for next year.

Table 1: Available Funds to the Company

Source	Amount
Reserve Funds	$ 12,802.08
John Deere Funds	$ 500.00
2014 Summer Matching Funds	$ 1,514.00
E-Council Funds	$ 3,000.00
TREP Funds	$ 8,000.00
Shell Funds	$ 2,000.00
OSGC Grant	$ 10,000.00
Traveling Team Member Contributions	$ 3,850.00
Matching Funds	$ 4,810.00
Donated Services	$ 1800.00
Total	**$ 48,476.08**

The company expenses are summarized below in Figure 4. The total costing of the ROV can be found in condensed form and in full detail in Appendix A. While the expenses for pool testing and STEM initiatives were under budget, the expenses for organization/tools and travel were over budget. Travel was over budget because of the always fluctuating flight costs. The decision to invest in tools that the team will be able to use for many years to come was what resulted in the organization/tools expenses to be over budget. The expenses for electronics and software, mechanical, and business materials matched well with the budgeted amounts shown previously. The total cost of the project was $36,008.

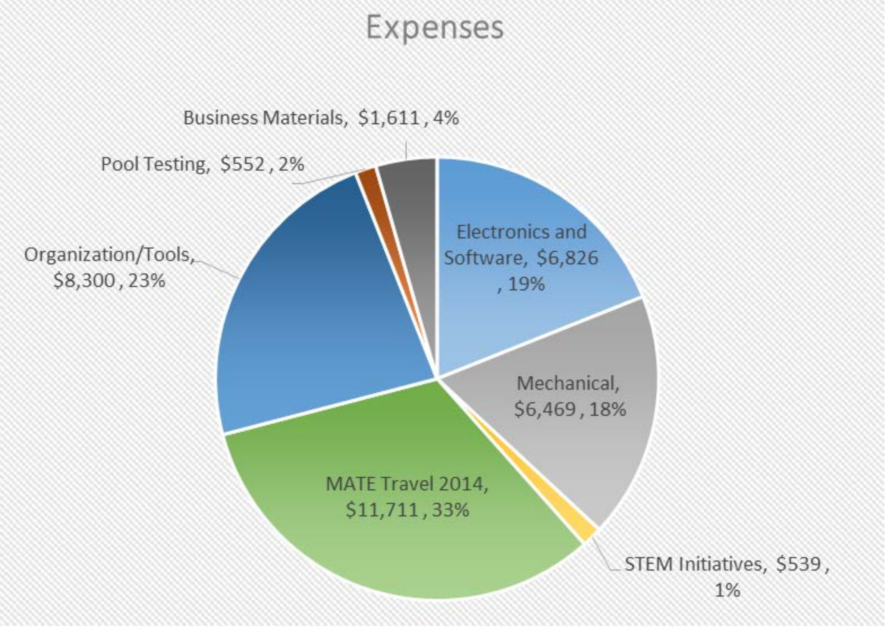

Figure 4: Expenses Pie Chart

3. Design Rationale

3.1 Mechanical

The design of this year's vehicle was based on knowledge gained over the past four years that the company has existed. The ROV constructed last year, shown in figure 5 to the right, was reevaluated and modified to have a larger inside diameter and improved seals for the rotating thrusters. Other noticeable changes include repositioning the rear thruster and adjusting the dome shape. The key features of the ROV are similar between the current and previous year, but every component except the mounting plate was re-designed. The new ROV was modeled using SolidWorks, a computer-aided design software. The parts that needed to be CNC milled were converted to a netCDF format using HSMWorks, which provided the mill with point-to-point movement instructions known as G-code.

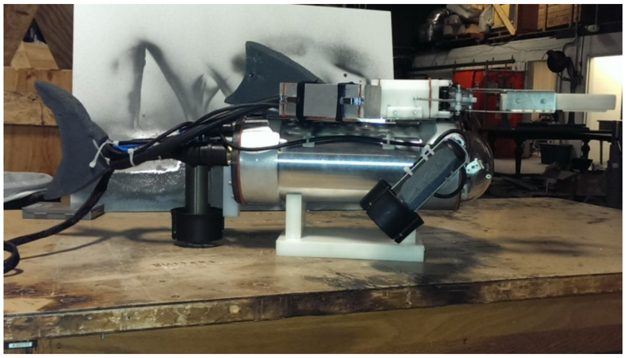

Figure 5: Picture of ROV from 2013-2014 year

The propulsion system for the vehicle consists of three CrustCrawler thrusters, which operate off of 48 volts. Brushless thrusters are more efficient and are capable of a higher thrust output compared to the thruster used previously. The high voltage corresponds to a lower current draw, shown by Figure 6.

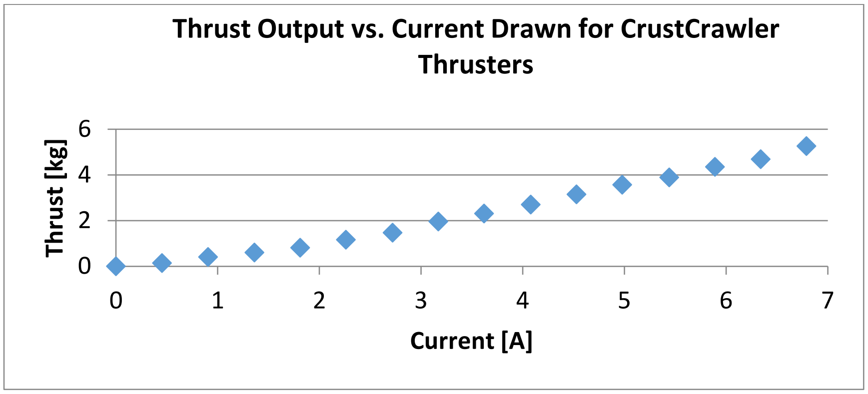

Figure 6: Graph showing thrust output vs. current draw for CrustCrawler thrusters

The vehicle's two forward thrusters are able to rotate 180˚ to allow for a traditional 6 degree of freedom control, as well as an airplane style flight control. The company chose this design because it results in a very versatile and agile ROV. Having rotating thrusters not only expands the ability for movement, but does so in a cost and space efficient manner. The rear thruster that was present in the previous iteration has been moved to the top of the chassis. This allows for a surge motion by the ROV as well as making the rear plate easier to remove. This has greatly reduced the time required to access the internal electronics of the vehicle. The thrusters can be seen in Figure 7.

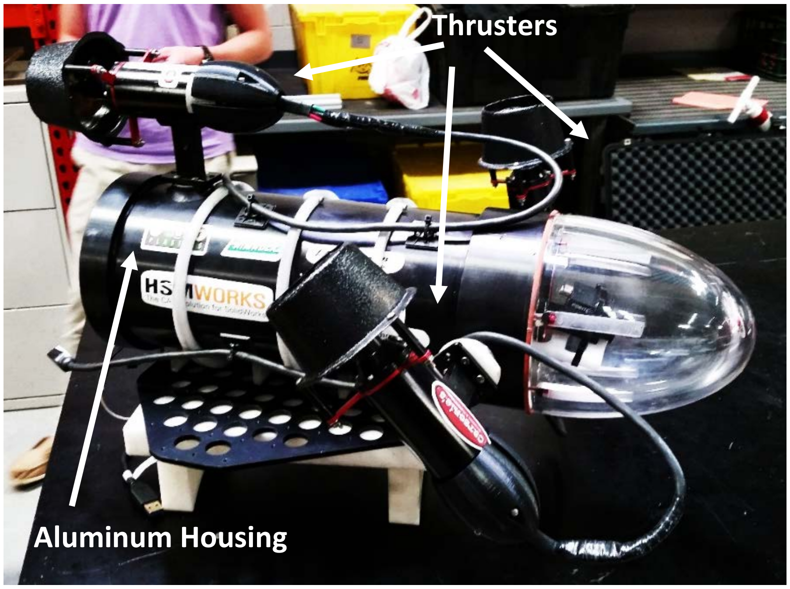

Figure 7: Picture of complete ROV

The main electronics housing, shown in Figure 7, is an aluminum cylinder. The material allows for heat transfer between the electrical components and the water, and the shape was chosen for easy machinability and its advantageous pressure vessel characteristics. The housing was machined on a lathe, allowing the inner diameter to match available stock for the electronics assembly. A mounting bracket for the top thruster, and sleeves for the forward thruster's bearings were welded to the exterior of the housing. The internal electronics supports were designed to freely slide around these locations to prevent interference caused by distortion due to welding. Micro Subconn connectors are used to connect the aluminum housing to the thrusters, cameras, and the tether. The small size of the connectors allows all of them to be placed on the rear plate. The rear plate and dome are sealed to the housing using gaskets, which is a method the company has successfully used in the past. There is a mounting plate attached to the aluminum housing for the attachment of various tool packages. This component was re-used from last year since it was still of adequate size.

The electronics plate, shown in Figure 8, was optimized for easy access and component mounting. The plate is made out of aluminum, for heat-sinking effects, and was water-jet cut for precision. The team can access all of the electrical components with ease by sliding them out of the aluminum housing by the rear plate.

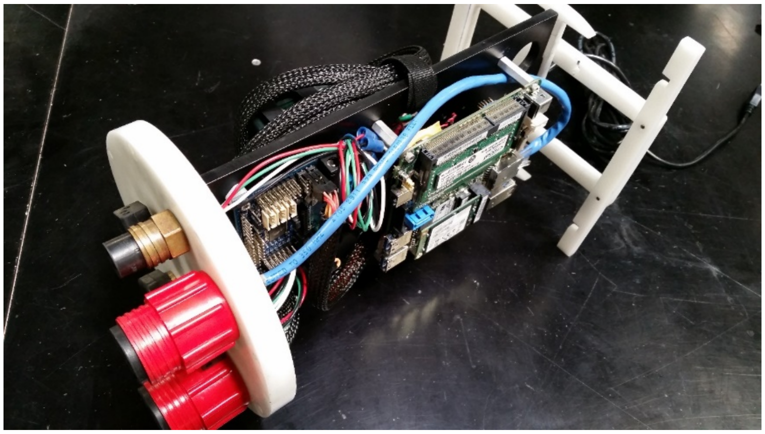

Figure 8: Photo of Electronics Plate

For this year's design, the company required a longer dome than what was commercially available. The dome was machined from a solid piece of acrylic stock to achieve the complex shape and to allow light to be transmitted through the material. The design was made to have a hemispherical tip with tangential parabolas extending to the cylindrical main housing. The technical computing to determine the exact shape of the dome was done using MatLab. The curve was then drawn in SolidWorks with a 12.7 mm offset to account for the desired thickness. HSMWorks was used to create G-code which was exported to our in-house CNC mill. This was the first part that we machined ourselves using the CNC mill. We were trained in its use as well as how to use HSMWorks by our machine shop supervisor. A camera will be located behind the dome so a consistent wall thickness is required across the entire part; any variation will negatively affect the video quality. The CNC mill is able to achieve these desired tolerances. The acrylic was vapor polished after machining was completed to produce a clear finish. A photo of the dome during the CNC process is shown in Figure 9.

Figure 9: Photo of dome on CNC machine

A single manipulator was designed to compete most of the designated tasks. The claw portion of the manipulator and the linkages were created using waterjet aluminum sheet metal. In the past, the team has had success using waterjet stainless steel for similar applications, but for this claw, aluminum was chosen because it is lighter and easier to machine. The claw is opened and closed using an aluminum air cylinder. The air cylinder uses 275 kpa air and is controlled by a four way, two position switch on the surface. Pneumatics was chosen over other power options due to simplicity of controls and the compact size of available air cylinders. In addition to this, because the pneumatic system has less moving parts than other possible methods, there is less chance for failure of the claw. Reliability was a major concern in the design because this is the only manipulator on the ROV. The air cylinder is attached to the claw and the ROV using Delrin® pieces that were machined using a bandsaw and a mill. Delrin® was chosen over aluminum because it is easier to machine and these parts will not encounter high stresses, so material strength is not as important. These parts were designed to be simple, such that inexperienced team members could machine them. A photo of the completed manipulator can be seen in Figure 10. A long arm was fabricated out of aluminum to extend the manipulator in front of the ROV to put the claw in view of the cameras. Several different attachments were designed to easily attach and detach to the end of the claw. With this modular design, the single manipulator tool can be used to great effect in all three of the simulated conditions.

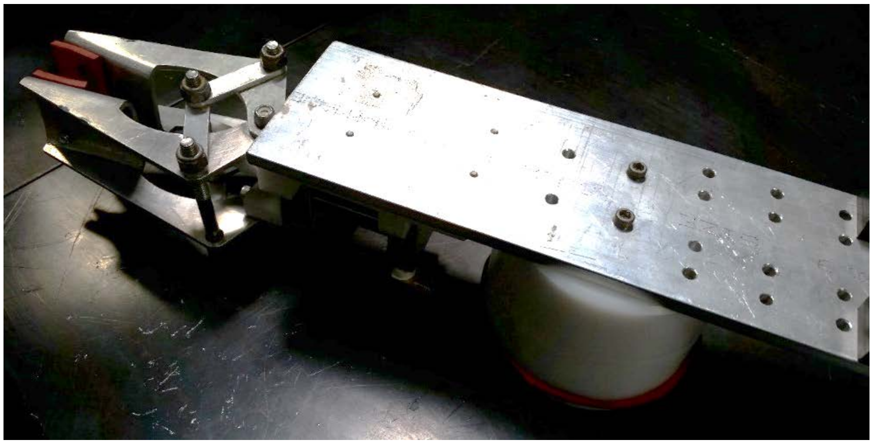

Figure 10: Photo of manipulator

The tether consists of 18 m of power, Ethernet, and air hose cable. The tether is wrapped in a protective sleeving so that it is contained and out of the way of the ROV. The surface connectors for the tether plug directly into the topside control station and the ROV ends are Subconn male connectors. A photo of the tether can be found below.

Figure 11: Photo of tether

For easy maneuverability in the water the ROV was designed to be almost neutrally buoyant, but slightly positively buoyant in case the ROV becomes inoperable. Due to the light-weight components and large electronics housing, the ROV is naturally positively buoyant and back heavy. To counteract this effect a ballast module is located on the bottom of the ROV underneath the manipulator mount. This module is filled with the necessary amount of stainless steel shot to get to the desired buoyancy level. The ballast module is shown to the right in Figure 12.

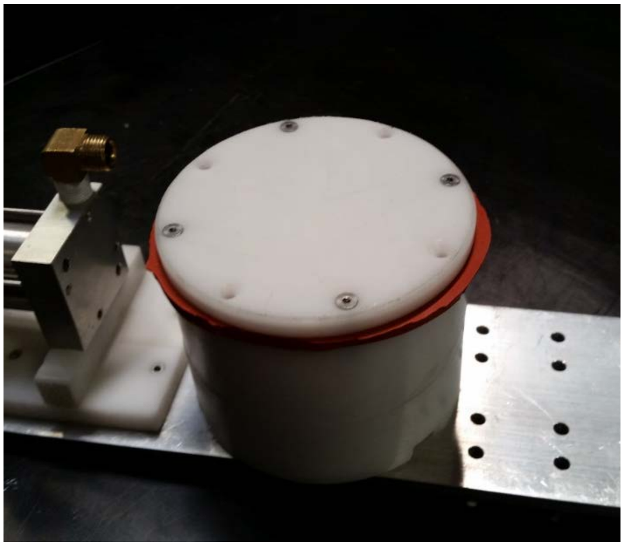
Figure 12: Photo of ballast module

The outside camera housings are made of aluminum and are sealed in the same fashion that the ROV is sealed. We chose this method of sealing because it has succeeded in the past and the company has a lot of experience with it.

3.2 Electrical

The electrical subsystem comprises the core of the ROV. This system is divided into three categories: controls/sensors, power, and actuators. These three categories work together under software control to make the ROV function. The first step in designing the electrical subsystem was determining the requirements of the system. This was influenced by the mechanical design: there needed to be thrusters that operated reliably, a way to control those thrusters, a camera or cameras, and a way to send and receive data from the ROV to the topside control station. These requirements result in a ROV that can easily be controlled and be flexible for different tool packages. Once these requirements were clearly defined, it was a matter of selecting components that met the requirements.

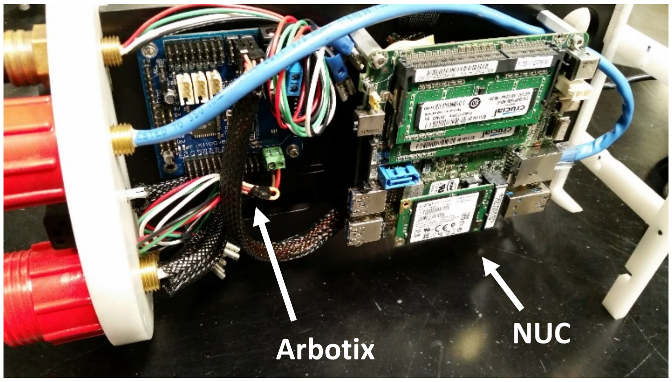

Figure 13: Photo of NUC and Arbotix

The brain of the ROV consists of an Intel NUC, a small computer (shown in Figure 13). This computer was chosen for its small form factor allowing it to fit inside a relatively small electronics housing. Additionally a NUC is a fully functional computer, allowing it to connect to a LAN over Ethernet and avoiding any software compatibility issues. In previous years we had attempted to use a Beaglebone Black running an ARM processor, but software compatibility issues limited its functionality. The NUC communicates with the topside control center and relays commands, via USB, to an Arbotix microcontroller (shown in Figure 13) that handles the peripheral communication to the hardware components. The Arbotix was chosen because it was designed to control the servos used to actuate the front thrusters. As well as controlling the servos, the Arbotix is used to send commands to the motor controllers. Three Point Grey B-FLY-U3 cameras and a LORD microstrain 3DM-GX4 inertial sensor (shown in Figure 14) are also connected to the

NUC. The data from these sensors are streamed over the LAN from the NUC, for the topside control station to pick up. The cameras were selected for ease of use: some basic software was available to access the cameras. The inertial unit was included to provide heading and some position data to the driver.

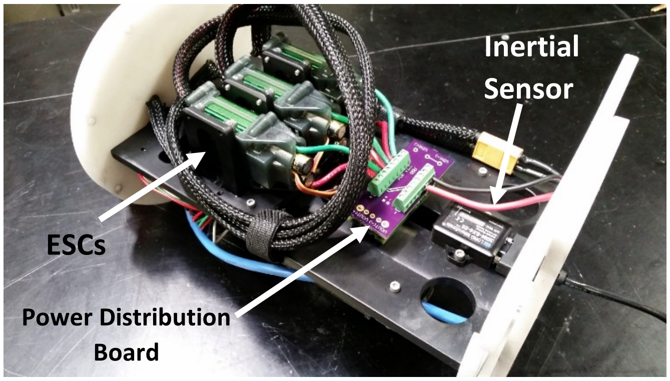

Figure 14: Photo of Power Distribution Board, ESCs, and IMU

The power category includes a 10A 48-12V DC to DC converter and three Phoenix EDGE HV60 UROV Firmware Upgraded Electronic Thrust Controllers. Power comes in to the ROV from the tether at 48 VDC. This input power is connected to a 20A circuit breaker on the surface. The Intel NUC, the Arbotix microcontroller, and the servos all require 12 volts to operate, so the 48-12V DC-DC converter provides this power. The 48 VDC power goes into a custom power distribution board (Figure 14), integrated with the DC-DC converter, sending 48 volts to the motor controllers and powering the Arbotix, the NUC, and the servos with 12 volts. The Phoenix thrust controllers (shown in Figure 14) were selected because they could handle the 48V unregulated, and Crustcrawler, the manufacturer of the thrusters, had optimized the firmware on the controller to perform well with our selected thrusters.

There are two types of electric actuators on the ROV, 400HFS-L Hi-Flow Crustcrawler thrusters and servomotors. The Crustcrawler thrusters were chosen because they utilized brushless electric motors, as opposed to DC motors. In previous years DC thruster motors were used, and performed well, however there were constant problems with the DC motor controllers. From outside experience from two of the team members, brushless motor controllers, or ESCs, were known to be extremely reliable. Thus the decision was made to move to brushless DC thruster motors. The servos were selected because they met the speed and torque requirements, and because there was a controller board, the Arbotix, specifically designed to control these servos.

The ROV communicates with the surface and receives power through the topside control station. It consists of an Intel NUC computer, monitor, power supply (for ROV testing), router, circuit breaker and connections for MATE input power. A photo of the topside control station can be seen to the right in Figure 15.

Figure 15: Photo of topside control station

The System Interconnection Diagram (SID), which illustrates how all of the electrical components are connected, can be seen on the next page in Figure 16.

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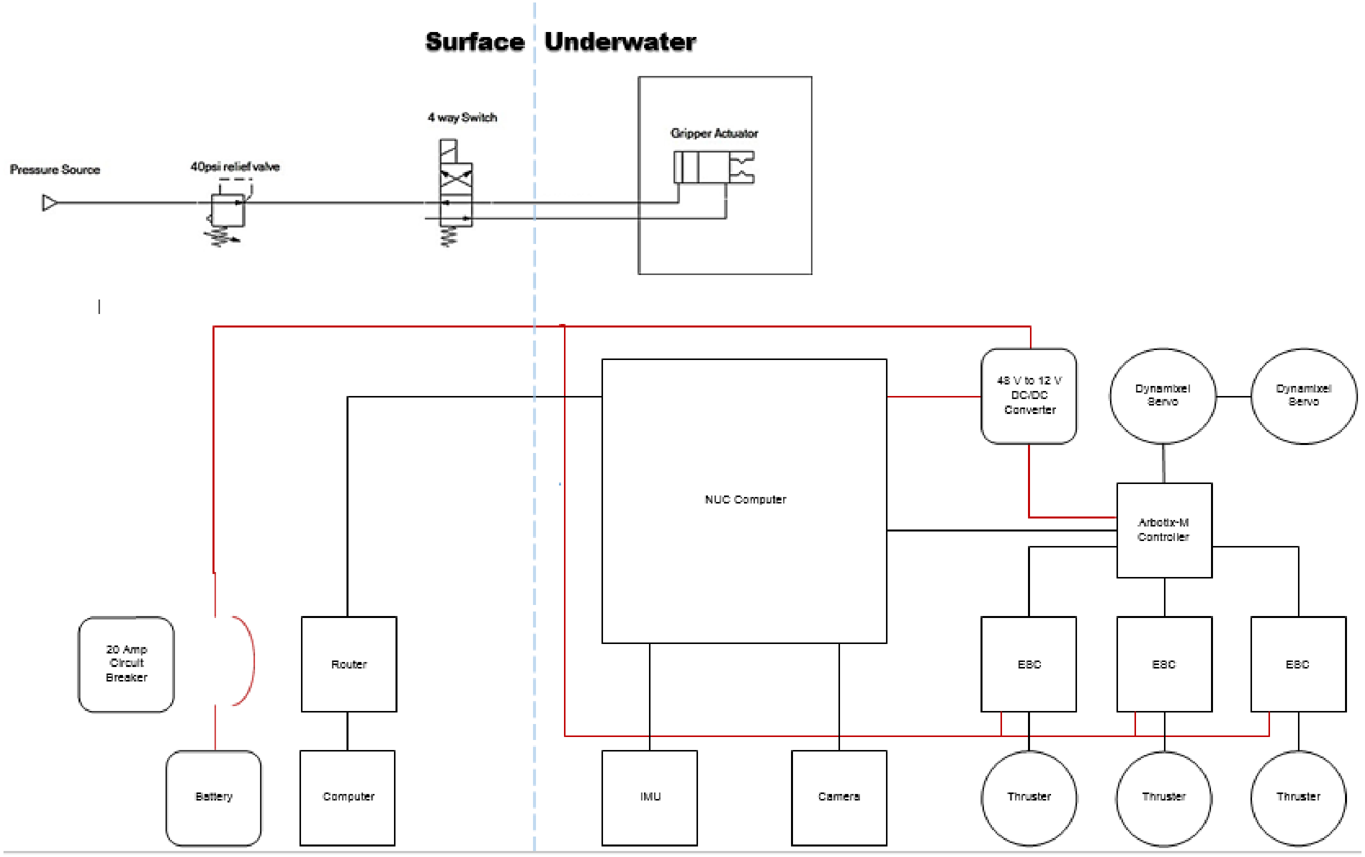

Figure 16: System Interconnection Diagram

3.3 Software

The software of the ROV consists of a topside control station with a router connecting the topside computer with the computer onboard the ROV. To communicate between the two, we took advantage of a powerful open source piece of software called Robot Operating System (ROS). ROS allows us to seamlessly program the robot using "nodes" which control certain systems throughout the operation. The input node (Figure 17) takes the Bluetooth controller input and converts it into usable data in a struct of arrays. We chose to use ROS because of the organization that is possible. In addition to being a widely used open source software, the programs written are designed to be very compartmentalized to make programming on a team an easy task and keep troubleshooting simple by analyzing one part at a time.

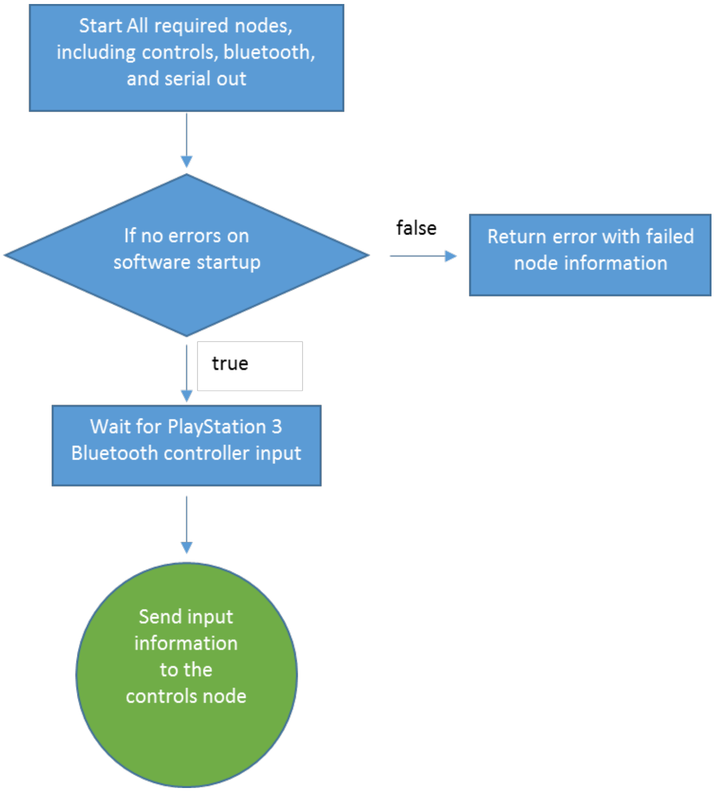

Figure 17: Input node, software flowchart

The beauty of ROS stems from the ability to quickly and easily communicate between nodes regardless if they are running on the same machine or not. The struct from the input node is passed to the controls node (Figure 18) which performs operations on the data that creates values that can be sent to the ArbotiX microcontroller. Next, the data is put into a different struct which contains all of the values that are being written to the two servos and three thrusters. ROS runs on both the topside computer and the onboard computer which are connected via the router. ROS has capabilities to run multiple machines under one network and allows them to communicate. Therefore, the middle man between the ROV and the topside is taken care of. The third and final node is running on the onboard computer which writes out to the ArbotiX microcontroller via serial port and writes the required values.

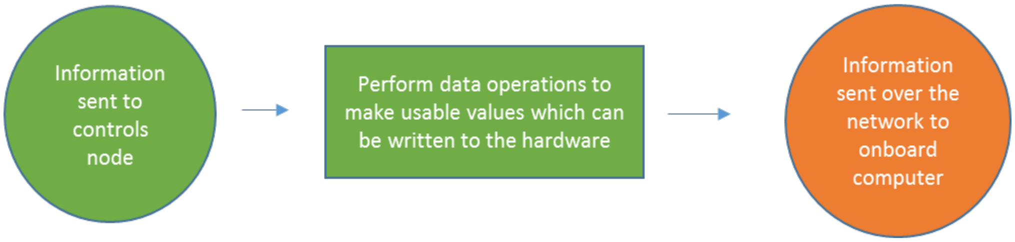

Figure 18: Controls node, software flowchart

The microcontroller is an invaluable part of the whole system. It controls the thrusters and servos directly via dedicated DYNAMIXEL servo output ports and PWM output ports. The ArbotiX runs a program (Figure 19) which constantly reads serial data from the computer. After writing the values, the program loops back to the start, waiting for input once again. This software operation occurs at 10 Hz.

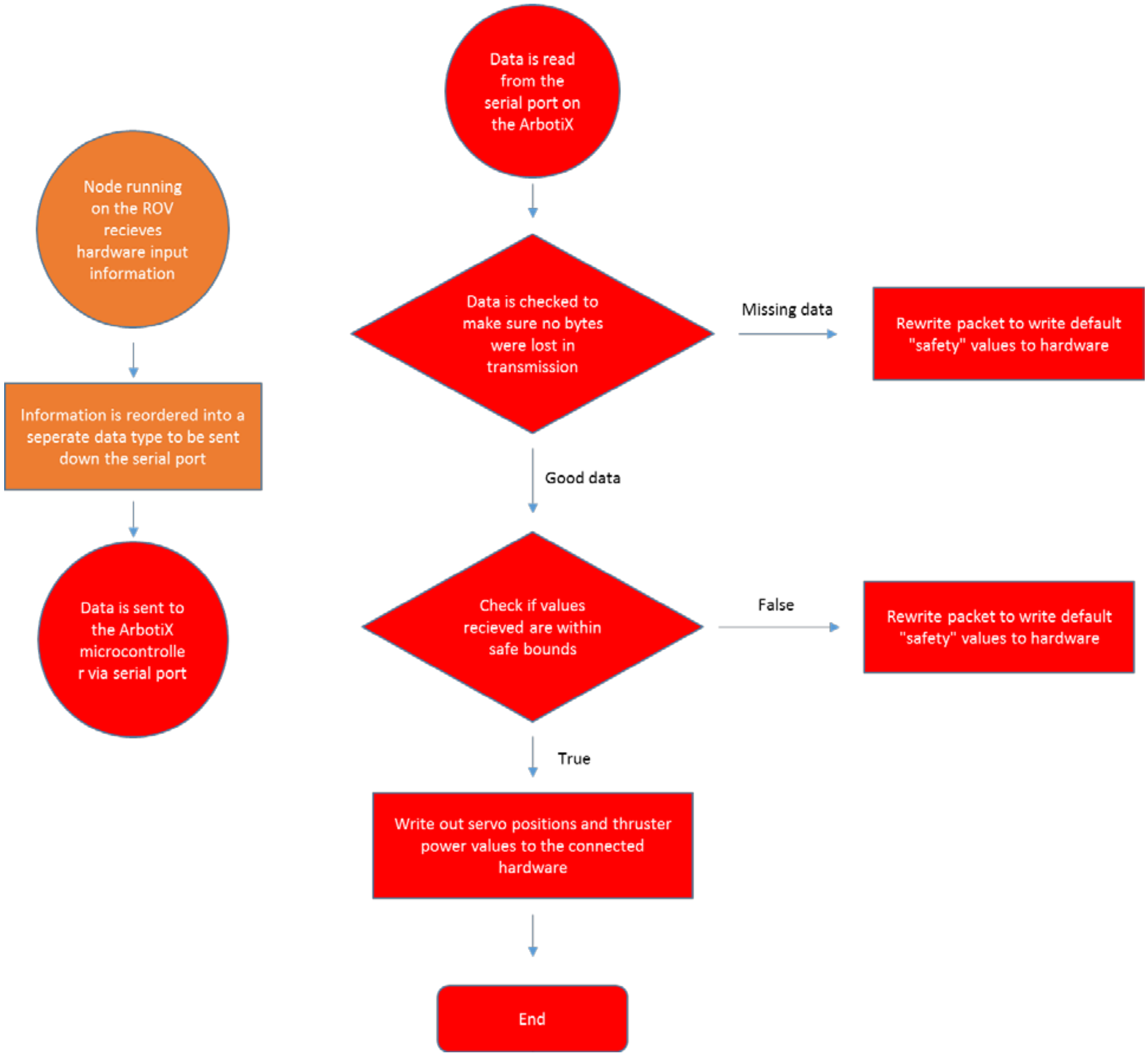

Figure 19: Arbotix, software flowchart

The completion of the tasks relies on the ability for the operator to understand the environment that the vehicle is travelling and operating in. The ROV uses three Point Grey cameras running on a USB 3.0 bus. In order to integrate it with the rest of our system, we created three more ROS nodes; the first which constantly reads the input video feed, the second which constantly broadcasts video and displays it on the screen mounted on the topside control station, and the third one which computes measurements of objects seen by the cameras.

4. Payload Description

The payload of the ROV makes it capable of completing the required tasks for the mission. The payload items and the tasks that each supports are summarized in Table 2 on the next page.

Table 2: Summary of tasks supported by each payload item.

Payload Item	Tasks Supported
Claw – No Attachment	Demo 1: Acoustic sensor deployment Demo 2: Valve turning, pin pulling, removal of corroded section, flange installation, wellhead cover removal and installation Demo 3: Valve turning
Claw – Ball Attachment	Demo 1: Algae and sea urchin extraction
Claw – Hot Stab Alignment Attachment	Demo 2: Hot stab insertion and removal
Claw – Hook Attachment	Demo 2: Gasket installation
Flowmeter	Demo 3: Flow rate measurement
Voltage Detector	Demo 3: Anode grounding testing
Lift Line	Demo 2: Removal of corroded section
Water Flow Driver	Demo 3: Move water through system
Camera Vision System	All measuring, CVI, survey tasks, and examinations

4.1 Claw and Attachments

The claw, as described in the design rationale section, is pneumatically powered and was designed to allow for various attachments. There are several tasks that do not require any attachments to the claw; however, for some of the tasks a more advantageous configuration is desired. Without any attachments the claw is able to clamp onto small and regularly-shaped objects, the ROV can then maneuver to the needed location to complete the task. Once the claw is positioned correctly, the claw can release its grip on the item to finish the task. The tasks that do not require an attachment are listed in Table 2.

In order to complete the algae (ping pong ball) and sea urchin (O-Ball) extraction tasks the Ball Attachment is utilized, as shown in Figure 20. Due to the spherical shape of the ping pong balls, the claw alone is not able to provide an adequate number of contact points. The design of the Ball Attachment was driven by the need for something that could provide support above and below the ball. The advantage of the spherical shape is that once the ping pong ball has been placed and the claw closed, it cannot escape. The sea urchin can then be extracted using the hook on the end of the Ball Attachment without having to return to the surface. These are the only tasks that require the claw for the first demo, therefore the attachment can remain attached for the entire mission run.

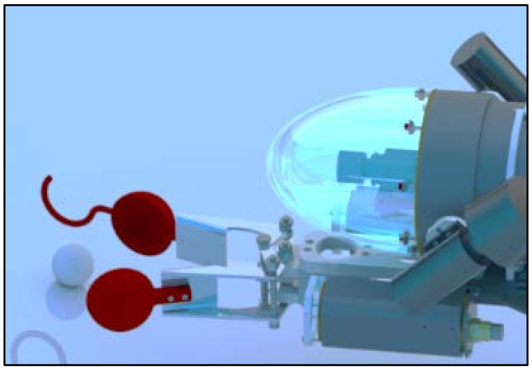

Figure 20: ROV with Ball

The Hot Stab Alignment Attachment (Figure 21) is used to complete the hot stab insertion and removal tasks. The Hot Stab is gripped by the claw and sits underneath the clear alignment plate. The attachment helps line the ROV up correctly with the port for quick insertion. The alignment plate is clear so that the camera can see the port during the insertion and removal processes

Figure 21: Photo of Hot Stab Alignment attachment on ROV

The hook attachment (Figure 22) is used for the gasket installation task. While this task could be completed with just the claw, the hook attachment allows for the wellhead protective cover to be held while the gasket is installed so that the cover can then be quickly re-placed. Without this attachment, the ROV would have to return to the surface to retrieve the gasket and leave the Wellhead Protective Cover at the bottom of the pool until the gasket was in place.

Figure 22: Image of ROV with Hook Attachment

4.2 Flowmeter

The flowmeter is an independent sensor that is deployed by the ROV to the seafloor. It will be deployed at the beginning of the mission to ensure that an accurate measurement is made. The sensor consists of a paddlewheel enclosed in a clear plastic enclosure, which is forced to turn from the water current. The circular side of the paddlewheel has a cover with a black and white pinwheel design. Through the use of a CDS cell, the changes in black and white colors are sensed and tabulated. By knowing the number of times the black and white colors are sensed the speed can be calculated. The paddlewheel assembly and CDS cell are mounted on a deployable sensor carrier for easy deployment, as shown below in Figure 23 on the next page.

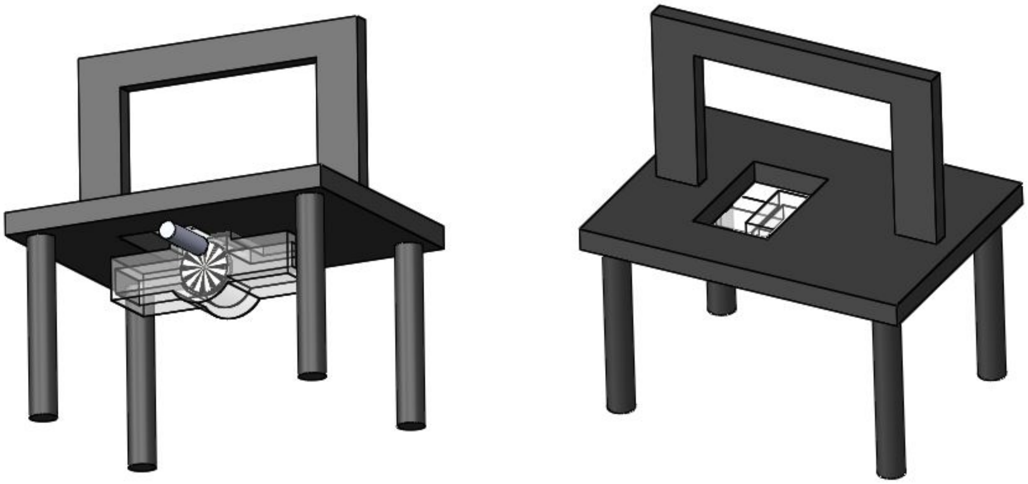

Figure 23: Image of Flowmeter (bottom and top views)

4.3 Voltage Detector

The Voltage Detector consists of a magnetic ground lead and a metal positive lead. Both leads are connected into a circuit that will measure the voltage across the leads. The magnetic ground lead will start in the claw and the positive lead will attach to the side of the claw. During the mission the ground lead will be attached to the common ground point and will remain there until it is picked up from the claw. The ROV will then maneuver to touch each anode with the positive lead and measure the voltage across. Once all measurements have been made, the magnetic ground will be removed. The voltage detector is shown to the right in Figure 24.

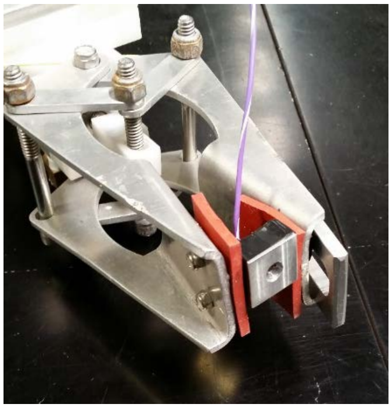

Figure 24: Photo of Claw with Voltage Detector

4.4 Lift Line

The lift line, shown in Figure 25, is comprised of a section of plastic pipe and a rope that goes to the surface. The material is flexible enough so that the piece can be pushed onto the corroded section, but once attached it is sturdy enough to hold the pipeline. Once the lift line is secure around the corroded section, it will be lifted by the rope to the surface.

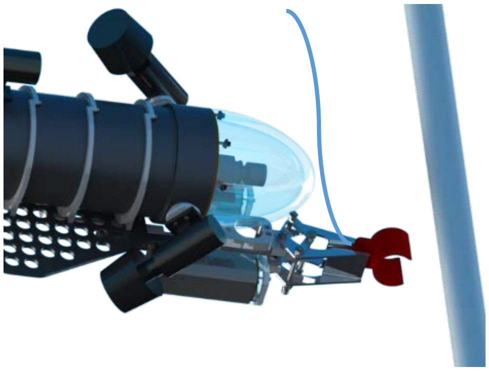

Figure 25: Image of ROV with Lift Line

4.5 Water Flow Driver

In order to check the functionality of the pipeline system, water needs to be pushed through the system. This will be accomplished by using the pressure force provided by a thruster. The aft thruster will be lined up with pipe inlet and will be powered forward, to counteract the movement from the thruster the side thrusters will be powered in reverse. The force that the thruster can provide is adequate to push water through the system and to the surface.

4.6 Camera Vision System

The camera vision system is one of the ROVs crucial tools. Not only does the system allow the pilot to view the surroundings of the ROV, but it also acts as a device to measure the various task-required components. There are three cameras located on the ROV, one for viewing the claw and two pointed forwards for measuring. The cameras used for measuring are placed at a known distance apart and known angle so that the true length of objects can be calculated. The software takes the raw footage, converts it to a point cloud, identifies the edges, and then calculates the distance. A photo of the camera can be found to the right in Figure 26.

Figure 26: Photo of Camera used on ROV

5. Safety

The ROV has many different safety features. A safety checklist that the company follows when testing can be found below.

<u>Safety Checklist:</u>

Prior to deployment of JAWS:

1. Check that all cables on the vehicle are secure and strain reliefs are tightened.
2. Check to make sure are bolts are tightened on main housing using a torque wrench.
3. Check insulation of tether cables.
4. Turn on top side station, but keep power to vehicle off.
5. Check that tether connections to top side are secure.
6. Flush the pneumatic lines beforehand and make sure that all valves are in the off position.
7. After vehicle has been placed in the water, power to vehicle can be turned on and pneumatic lines live.
8. Before retrieving vehicle from the water, ensure that power to the vehicle is off and pneumatic lines are exposed to the ambient source.

9. Although retrieval of the vehicle can be performed by a single individual, it is recommended that two people lift the vehicle whenever possible.

10. After retrieval, the vehicle should be inspected for leaks.

5.1 Software Safety Features

The Arbotix has a timeout so when it loses connection for more than few seconds it will safely turn off the thrusters and align the servos in the default position coplanar with the central axis of the ROV. Additionally, the ArbotiX serves as a software-side safety mechanism for controlling the current draw of the ROV. If the power values being asked to write to the thrusters are too high, the system will automatically scale them down so the thrusters won't overdraw current and cause damage or a safety hazard.

5.2 Electrical Safety Features

The DC Power converter has over-current and reverse polarity protection, along with a heat sink connected directly to the aluminum electronics plate for fast heat dissipation. In the topside control station there is a 20A circuit breaker that protects the entire system for high current draw. The team members use ESD mats while working with electrical components and wear safety glasses while soldering. Safety is of the upmost important in the company's workspace.

5.3 Mechanical Safety Features

The thrusters of the ROV come equipped with safety enclosures around the propellers to ensure that no fingers are in danger during testing. Within the tether there is a strain-relief line in case the ROV needs to be pulled to the surface. This safety feature ensures that no cables in the tether get pulled in such a fashion that water would be able to enter the ROVs electronics housing. All members of the mechanical team that manufacture ROV components have gone through intensive safety training on all of the machines in the shop and always wear safety glasses when in the shop.

6. Troubleshooting Techniques

When the company runs into a problem, technical or non-technical, it follows the following troubleshooting techniques.

1. Isolate the problem to ensure there will be no confounded results
2. Determine the extent of the problem
3. Communicate with team members how the problem may effect or be helped by them
4. Determine and execute a plan to fix the problem
5. Follow-up with the problem and involved team members to ensure the problem has been fixed

When a problem is identified the error may not reside in the apparently faulty module. Team members have to work backward from the apparently faulty module, looking for a module with a good input and bad output, whether that module is a piece of software or hardware. Once the faulty module is identified, the correct testing can be identified. System interconnection diagrams and algorithmic flow charts are the primary tools for identifying modules and determining what constitutes a good input or output. Once the faulty module is identified, the team can take whatever action is necessary to restore or improve that component whether it is a mechanical modification, electrical component or software system.

6. Challenges

One of the challenges the team faced this year was an unexpectedly wide manufacturing tolerance for the thrusters. When first placed in water, the ROV spun itself in circles whenever equal throttle was applied to both forward thrusters. Careful observation revealed that both thrusters were operating, though one was spinning much faster than the other. The team first hypothesized a minor variance between the two thrusters. To account for this variance, a software routine was created to allow the thrusters to be calibrated. As the faster thruster fell below 80% of the other without a visible improvement in operation, the team realized the variance was significant enough to warrant the construction of a test stand (shown in Figure 27) and a series of tests to compare the thrusters. For completeness, all three thrusters were tested. It was found that the port thruster could only provide half the power of the starboard thruster. Fortunately the aft thruster was found to have a comparable output to the starboard thrusters. The half power thruster was moved to the aft position leaving the forward pair in balance. The next time the ROV was in the water it was able to travel straight ahead.

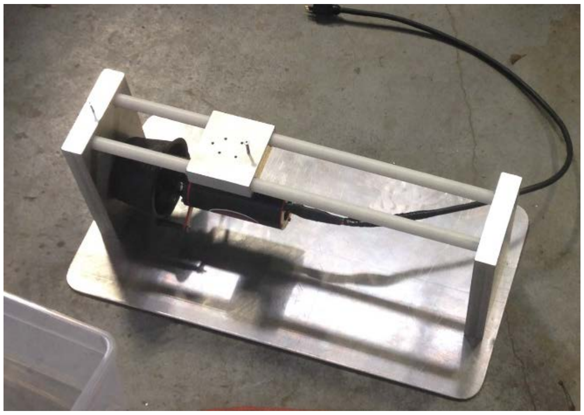

Figure 27: Photo of thruster test stand

7. Lessons Learned

As we explored various facets of engineering, one discipline became a primary focal point - manufacturing. It quickly became learned that designing a component in CAD, wasn't the same as actually making the component. And thus, limitations in manufacturing techniques should be reflected in the design.

In the beginning of the year, this led a considerable amount being spent on manufacturing an acrylic dome. Given that this is in the optic path of the camera, tolerances become extremely tight. Thus computerized numerical control (CNC) is critical. As an axisymmetric component this part was most suited for a CNC lathe. However we did not have access to such a machine. As such, the part was machined on a vertical CNC mill. This led to some problems. First and foremost, the part was milled using a ball end mill and really fine passes were needed to create an acceptable finish. This led to a very long machine time and was not an economic use of time. Secondly, the machine was unable to access the center of the dome, which led to a small flat in the interior of the dome. This is critical as changes in thickness lead to distortion and thus more effort is needed to correct the camera image.

A better solution would have been to remove the round cone of the dome to a flat. This would allow for little distortion, faster production of parts and simpler jigs. Although the part functions as is, future designs will be constructed with the experiences gained this year.

The team also learned a lot about communication this year. Over half of the team were new to the team this year, which provided the company with a challenge. In order to effectively transfer information from senior team members to the new team members, team leaders had to form a new strategy. New team members needed projects that challenged them enough so that they could ask questions, but not too challenging that they did not know where to start. The company found that the best way to do this was to pair new members with a senior member for their first project. This method worked great and will be used in the future.

8. Future Improvement

The team's current design could most be improved by altering the orientation of the aft thruster. The thruster's current longitudinal orientation provides a surge force as well as a pitch torque when operated. The surge force is rendered redundant by the ample force provided by the forward pair of thrusters. It is also present whenever a pitch torque is called for, requiring the forward thrusters to be used to cancel that force when it is undesired. Mounting the aft thruster vertically would remove the undesired surge force and increase the pitch torque. This increased pitch torque would be quite useful in counteracting the torques of objects in the claw and increase responsiveness of attitude control. Furthermore, not running the forward thrusters to cancel the aft when only pitch torque is called for would represent an improvement in energy efficiency.

The team would also like to design its own thrusters in the future. It would seem that there is not a product that perfectly suits the company's needs available and it may be in the company's best interest to invest in our own means of propulsion.

9. Reflections

"Five years ago, our team set out to build a remotely operated vehicle using common plumbing material, such as PVC and to be innovative, our vehicle was going to be hexagonal, painted grey and a bright red, the Buckeye Boulder lived up to its name. Despite not having a way to control the vehicle, it sank pretty well. As you can imagine, we weren't able to compete that year. Our goals were uninspired, and our vehicle followed suit.

Yet a few years down the road, our vehicles evolved dramatically, from carbon fiber, to acrylic, to aluminum. And I think that there are two reasons as to why. As young collegiate students, we still wanted to do everything without doing anything. But as our team grew, we realized that a vehicle wouldn't build itself. It's a concept you wouldn't think you needed to explain to engineers. But perhaps because of our confidence or because we chose to forgo this fact, our team was a bit more immature.

This year, we challenged ourselves in every aspect - from controls to manufacturing and design and perhaps more importantly, we worked to achieve them. Our vehicle has three thrusters with the capability of five. And this year we machined the dome, which is an optical component and thus held to extremely tight tolerances. Our controls have a bit to go and the dome could use some work. But, I didn't ever think that our team would get this far. The second reason is discipline. Our first years, our space was disorganized and our meetings weren't very focused. This year, every meeting has a clear agenda and finding the appropriate tools is very much streamlined. This year, the size of our team increased dramatically and thus communication between one another became more non-trivial. One way to *facilitate strong communication is an organized structure. This way, our tools on online storage facilities (such as Box) were clear and concise.*

It still amazes me that today when we go to set our goals, they are far more ambitious. We have set ourselves with a strong foundation upon which we can succeed. I say this every year, but I am proud of our work this year, and somehow the saying becomes truer with each passing year."
– Achal Singhal

"My name is Erika Klek, a rising sophomore on Ohio State's Underwater Robotics Team. As a first year engineering student with no previous robotic experience, joining a club with knowledgeable upperclassmen was intimidating. Some of the concepts were abstract, as I have never experienced such a large project with so many individual components. However as time progressed, I was able to understand how different parts of the robot came together in order to create a fully functioning machine. One of my tasks included designing a power distribution board. The design was accomplished using EAGLE CAD. Although my design did not succeed, my prowess of the software exponentially increased. I also learned how important teamwork is; this project would have been impossible to create without several people on both the electronics team and the mechanical team. My favorite meetings throughout the year included pool testing and soldering. Although there were some tedious meetings, which included constructing and deconstructing the tether and stripping extremely small and delicate wires, I gained knowledge that will be used throughout my classes and further projects."
-Erika Klek

10. References

Collins, J. A., Henry R. Busby, and George H. Staab. *Mechanical Design of Machine Elements and Machines: A Failure Prevention Perspective*. Hoboken, NJ: Wiley, 2010. Print.

Moore, Steven W., Harry Bohm, and Vickie Jensen. *Underwater Robotics: Science, Design & Fabrication*. Monterey, CA: Marine Advanced Technology Education (MATE) Center, 2010. Print.

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1. Ohio Space Grant Consortium (financial support)
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3. Marine Advanced Technology Education (MATE) Center (providing competition)
4. Ometek (donation of machining services)
5. Danco (Donation of anodizing services)
6. HSM Works (financial support for software licenses)
7. The Ohio State University College of Engineering (financial support, student org. support)
8. Center for Automotive Research (providing project workspace)
9. John Deere (financial support for food)
10. Carsonie's (food donations)
11. Chipotle (food donations)
12. LMS (donation of team shirts)
13. Honda (benefits through Honda-OSU partnership)
14. Rimrock Corp. (donation of machining services)

Appendix A

🟦 Reused
🟩 Donated

Electronics Team		
Description	**Quantity**	**Total Costs**
Various Connectors	N/A	$ 43.70
Various Cables	N/A	$ 180.58
3 PointGrey Cameras and Lenses	N/A	$ 1,166.41
Various Electrical comp.	N/A	$ 296.80
ESD mat	1	$ 165.88
Tether Components	N/A	$ 432.67
Brushless Motor Controller	3	$ 449.85
AHRS Sensor	1	$ 1,895.00
Power-One DC/DC Converter (48-12V) Baseplate	2	$ 130.38
SONY DualShock 3 Wireless Controller Black	2	$ 89.98
Crucial 8GB DDR3 1600 Laptop Memory	1	$ 71.99
Crucial M500 120GB Mini-SATA InterN/Al SSD	1	$ 74.99
Intel BOXD54250WYK NUC	1	$ 349.99
OpenCM9.04 + Shipping	1	$ 36.09
Subconn Connectors	1	$ 1,319.44
RoboController + Shipping	1	$ 47.94
ArbotiX-M Robocontroller	1	$ 39.95
Total		*$ 6,826.20*

ROV/Mechanical		
Description	**Quantity**	**Total Cost**
Mounting Plate	1	$ 100.00
Subconn Connectors -4-pin male and female	2	$ 160.00
Anodizing	N/A	$ 500.00
Machining	N/A	$ 1,000.00
Polishing	N/A	$ 300.00
Various Bolts	1	$ 202.97
Subconn Connectors	N/A	$ 367.54
Aluminum Stock	N/A	$ 178.09
Various Shafts and Rods	N/A	$ 111.01
Plastic Stock	N/A	$ 1,064.61
Tools	N/A	$ 352.64
Waterjet Cost	N/A	$ 400.00
Fittings/Couplers	N/A	$ 360.60
SS Balls	2	$ 115.90
Pelican 1660	1	$ 282.76
CrustCrawler Shipping	1	$ (50.00)
ESCS	3	$ 207.00
Servos	2	$ 439.80
Thrusters	1	$ 1,797.00
Clear Lexan Dome 1/4"x5-1/2" (backup)	1	$ 94.50
Pop-Safety Valve, 40 psi	1	$ 5.26
Shipping	1	$ 5.26
1/4" ID, 3/8" OD, 1/8" Width Double Shielded Ball Bearing	6	$ 31.68
EPDM AS568A-224 O-ring	1	$ 6.20
Stainless Steel Springs	1	$ 8.56
Air Cylinder	1	$ 68.44
4-Way Solenoid Valve	1	$ 71.39
Shipping for Anodizing	1	$ 68.42
Shipping Cost	1	$ 164.00
Total		*$ 8,529.00*

MATE Travel 2014-15		
Description	**Quantity**	**Total Cost**
Shipping	1	$ 1,000.00
Hotel	1	$ 2,750.95
Airline Tickets	1	$ 7,810.50
Registration	1	$ 150.00
Total		*$ 11,711.45*

Pool Time		
Description	**Quantity**	**Total Cost**
Pool Time (Dive Well)	4	$ 260.00
Pool Time (Dive Well)	19	$ 251.75
Pool Time (Dive Well)	3	$ 39.75
Total		*$ 551.50*