D.A.R.T.

DREXEL AQUATIC ROBOTIC TECHNOLOGIES

A.D.A.M. ROV

AQUATIC DIAGNOSTIC ACQUISITION MEASUREMENT

Technical Report

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I. ABSTRACT

Drexel Aquatic Robotic Technologies (DART) consists of fourteen employees from business, math, and engineering backgrounds who are passionate in developing the next generation of innovative and cost effective remotely operated vehicles (ROVs). The company has developed a solution to satisfy the request of The Applied Physics Laboratory (APL) at the University of Washington for proposals (REP) of an ROV that can conduct tasks in saltwater and freshwater environments in the Pacific Northwest. DART has spent over eight months in research and development to create the ADAM (Aquatic, Diagnostic, Acquisition, and Measurement) ROV. ADAM ROV can perform surveys of vintage aircraft wreckage, recover the aircraft's engine, install and recover a seismometer, install a tidal turbine, and install instrumentation to monitor the environment.

This is DART's first year in operation, and so ADAM ROV is built upon the comprehensive research and past experiences of employees. DART created an onboard control system to reduce tether weight and increase modularity of the electronics tube. The company used in-house development of components via 3D printing for rapid prototyping and cost reduction. Cross-disciplinary collaboration between the mechanical and software divisions yielded a compact and sophisticated ROV with a high degree of durability and functionality. The electrical division experimented with various system integrated diagrams to improve efficiency of the power distribution system of the given power supply to ensure minimal voltage irregularities.

Through the collective effort of DART's employees, ADAM ROV is the most suitable ROV to fulfill The APL at the University of Washington's REP.

*Figure 1: Back Row (Left to Right): Prem Patel, Jay Dave, Louie Feldman, Adam Schiavone, Arjun Pillai, Jacob Joseph, and Nate Albuck;
Middle Row (left to right): Adam Feldscher, Jose Arguelles, Paula Klichinsky, and Sarah Larkin;
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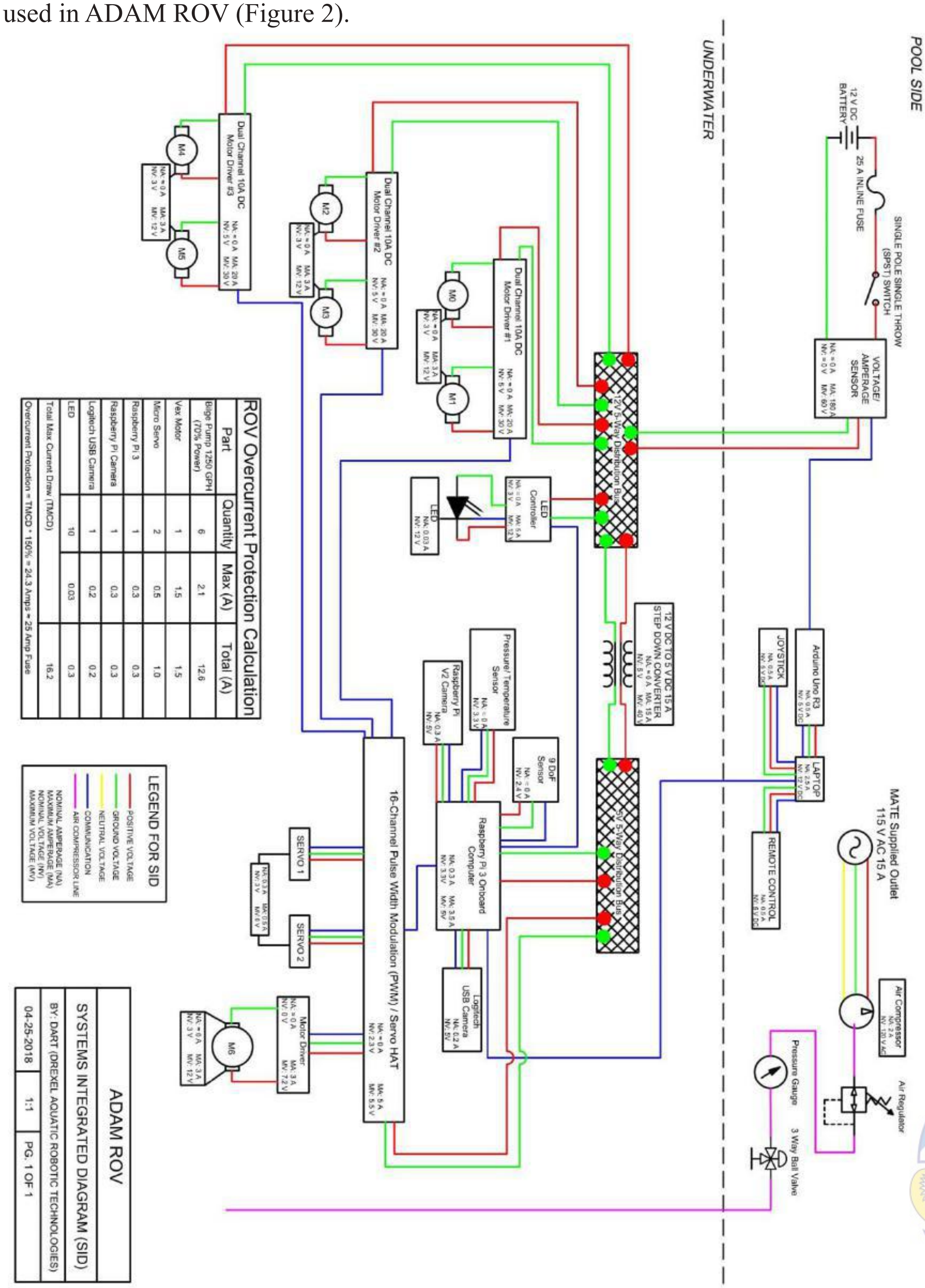
II. DESIGN RATIONALE

A. System Interconnection Diagram (SID)

The following are system interconnection diagrams of the air compressor lines/fittings and electronic systems used in ADAM ROV (Figure 2).



ROV Overcurrent Protection Calculation

Part	Quantity	Max (A)	Total (A)
Bilge Pump 1250 GPH (70% Power)	6	2.1	12.6
Vex Motor	1	1.5	1.5
Micro Servo	2	0.5	1.0
Raspberry Pi 3	1	0.3	0.3
Raspberry Pi Camera	1	0.3	0.3
Logitech USB Camera	1	0.2	0.2
LED	10	0.03	0.3
Total Max Current Draw (TMCD)			16.2
Overcurrent Protection = TMCD * 150% = 24.3 Amps ≈ 25 Amp Fuse			

Figure 2: System Interconnection Diagram (SID) of ADAM ROV

B. Vehicle Core System

1) Mechanical

<u>Frame</u>

ADAM ROV's frame implements a non-traditional design utilizing a cylindrical enclosure for the frame and buoyancy rather than employing a rectangular design for the frame and foam for buoyancy. Simplifying the design enabled the ROV to be nimbler when operating, smaller in size, and reduced the number of possible error sources. The watertight enclosure was purchased from BlueRobotics because of the reliability and durability of the product, which is critical to the success of the design since it will be housing the ROV's onboard control and communication electronics. The enclosure has a spherical dome in the front and connects to a casted acrylic tube which allows the water to be easily displaced above or below the dome to flow the water flat across the cylindrical tube causing the reduction of the frictional drag on the ROV (Figure 3). The reduction of the frictional drag will decrease the load on the thrusters to propel the ROV in which would reduce current draw and increase battery life in the field. Through the use of a cost-benefit analysis, the frame design was justified in incorporating Polylactic acid (PLA) 3-D printed elements to reduce both the cost and the weight of mounted components compared to other materials such as aluminum and Polyvinyl chloride (PVC), while not compromising the integrity of the frame.

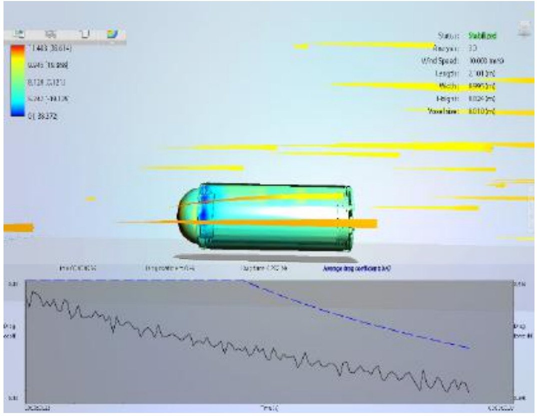


Figure 3: Flow Analysis of Frame Design

PLA was selected over other plastics such as nylon due to its lower price, rigidity that mounting elements require, and rapid prototyping ability. Bending and fracture analysis were performed on each mounting component part to find its yield and tensile strength ensuring and increasing the reliability of the mounts. Testing was also performed in regard to the fill density of each 3-D printed part from 10-30% in order to identify the optimal fill of material. The optimal fill was determined to be 15% because it minimized the volume and met the requirements of the generated forces. The 3-D printed clamps and mounts were designed with M8 holes for increasing serviceability as payloads can be mounted and repaired easily due to the integration of 3-D printing and optimal attachment point locations.

The casted acrylic enclosure of the ROV's body required circular clamps to be fabricated serving as a mounting interface to the tube from any of the attachments. The clamps around the ROV provide anchor points for mounting brackets through the threaded M8 holes that were printed inside of the clamps (Figure 4). The clamps and

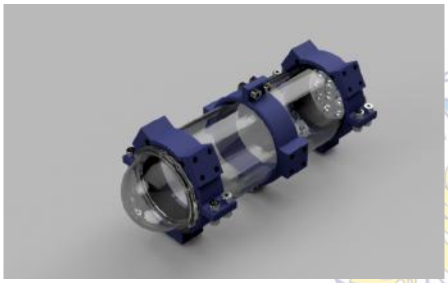


Figure 4: Rendering of ADAM ROV's Frame with Clamps

brackets were designed to minimize the volumetric footprint and additional drag which was conducted through bending moment analysis and curving all edges to permit ease of water flow around the clamp or bracket. Due to low friction of the PLA and acrylic enclosure, the two surfaces are coated with a layer of rubber to increase friction and keep the 3D printed components from sliding on the low friction surface of the enclosure.

Buoyancy

To compensate for the weight of the frame, manipulator, and electronic components, ADAM ROV's design significantly considered the various size enclosures available. The size of the enclosure was selected around three main factors: net buoyancy force generated (Archimedes' Principle), dimension requirements of the electronics configuration, and neutrally buoyancy. The theoretical buoyancy force includes the volume of all the external components of the ROV, which were calculated by the 3D modeling software. The other constants such as specific weight of water, mass of ROV, and gravity were collected and researched to find the net buoyancy force generated. The optimal enclosure size is a 101.6 mm diameter tube because it generated a net buoyancy force closest to zero. The controllability and maneuverability greatly increase as neutral buoyancy is achieved due to the equilibrium of forces on the ROV allowing the thrusters to be the singular applied force in creating a movement.

Propulsion

ADAM ROV is powered by six 1250 Gallon per Hour (GPH) Bilge pumps from SPX. Instead of configuring the thrusters in a traditional linear direction to achieve full thrust, an OMNI drive was implemented. The OMNI drive involves four thrusters rotated with a 45° offset from the horizontal axis and 10° from the vertical axis to produce a force in two dimensions. Originally, these four thrusters were not vertically offset. The offset angle from the horizontal and vertical axis was optimized through vector analysis to ensure maximum sway, surge, yaw, and pitch thrust without greatly decreasing one another. Through testing and practice, we found that these angles were necessary for precise movements underwater. Two thrusters fixed in the vertical axis allowed for heave and roll movements, which are located at the center of gravity of the ROV to take full advantage of the thrust (Figure 5). An important design consideration was placed on maximizing propulsion by developing protective shrouds that not only protect the marine life environment but also minimize the obstruction of water flow. It was desired to prevent obstructing water flow since this could cause the thrusters to be ineffective and increase the current draw. This OMNI configuration with the proper mesh guards equips ADAM ROV with six degrees of freedom, allowing to strafe in any direction.

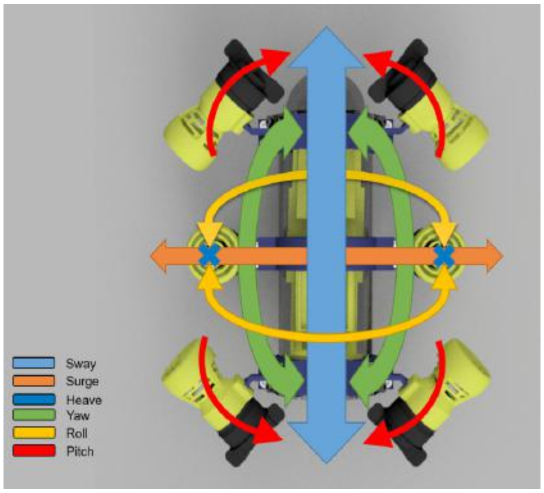


Figure 5: ADAM ROV's Six Degrees of Freedom

2) Electronics

ADAM ROV’s electrical system provides power and communication among all servos and sensors. In addition, the system includes three dual channel brushed thruster drivers that utilize a sixteen channel pulse width modulation (PWM) controller and a Raspberry Pi 3 Model B. This microcontroller was preferred over other conventional single board computers (SBC) due to its robustness, low price point, and compact design. The configuration of the electronic components was selected after careful deliberation of the custom electronic plate dimensions and ring terminal connections within the enclosure. The electronic plate housed in the enclosure creates a centralized architecture for the electrical system (Figure 6), which enables a singular location for maintenance, troubleshooting, and any potential issues.

Figure 6: Centralized Electronics Housing

ADAM ROV’s stable power distribution allows for up to four thrusters to be simultaneously controlled via the thruster drivers. The on-board sensors and lighting are integrated into the ROV’s system through the Raspberry Pi, which permits the ability to automate and assist the pilot when operating the vehicle. As a result of integrating many of the systems into a central processing unit, the communication and power distribution lines are minimal, creating a lightweight and cost-effective tether.

Power Distribution

ADAM ROV’s primary source of power is a 12 VDC battery that is transmitted from the surface through the tether to the first dual bus bar. The ring terminal bus bar inputs the initial power from the surface and distributes the output power to the three-dual channel brushed thruster drivers. The fourth output ring terminal set from the 12V DC bus bar is supplied to a 12V-5V converter which inputs the 5V to a second dual bus bar (Figure 7). The four outputs of the 5V bus bar powers the feedback and control devices such as the microcontroller, sensors, and servos. The bus bars create a parallel system that reduces the probability of voltage spikes and resistance along all the electrical components. This ensures equal distribution of power under any loading setting and prevents any overcurrent causing the system to fail. A commercial bus bar was utilized due to the expanded feature set and lower monetary and time cost than an producing a custom in-house bus bar design. As an extra safety measure, a self-recovery fuse was implemented on the 12V-5V converter so if it is tripped, the ROV will close the circuit to minimize damage within the system.

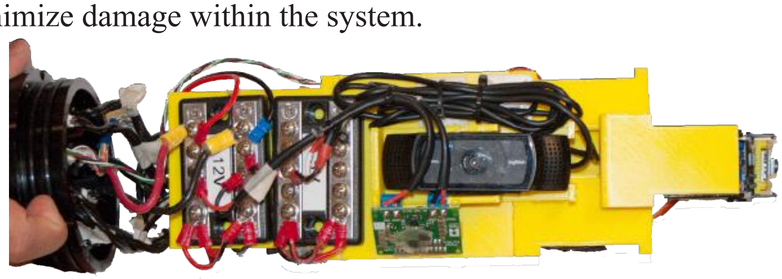


Figure 7: Power Distribution from the Source to Both Buses

<u>Cameras</u>

Due to the design of ADAM ROV's frame and propulsion, a dual camera system was incorporated to ensure maximum field of vision (FOV) and environment safety. The Raspberry Pi V2 camera was installed inside the dome on a tilt and pan servo system allowing the primary camera to tilt and pan in any direction needed up to 180° from the initial axis. Raspberry Pi V2 camera is equipped with an 8 megapixels (MP) lens and 1080p video capabilities but a 130° FOV. Originally, the camera had a very limited 42° FOV, and we realized when practicing in the water that this was not enough. We then introduced a lens that increased our FOV while also fitting inside our dome without making any contact when tilting or panning. The utilization of tilt and pan system improved the overall control of the ROV by providing multiple video angles to the pilot without moving the ROV. By utilizing this system, the battery and time trade-off would lead to better execution by reducing the amount of ROV movement causing less current draw and increase the time for operational tasks. The small size and easy integration of the Raspberry Pi V2 camera and the Raspberry Pi was the justifying factor in choosing this device over other brands of USB/ribbon cable video cameras. The secondary camera was fixed underneath the ROV to allow the pilot to navigate safely around the marine environment. The safety factor of the secondary USB camera was the driving force behind the decision in guaranteeing the ROV can survey the environment before, during, and after all missions are completed without any damage to the environment or organisms. The high definition and autofocus features of the Logitech USB C920 gave the best cost-over-quality trade-off, greatly aiding the pilot with clear and consistent video at all times.

<u>Tether</u>

Figure 8: Cross Sectional View of ADAM ROV's Tether

ADAM ROV's tether consists of multiple cables shielded by a Polyethylene Terephthalate (PET) braided sleeving to create a single flexible protective casing with a diameter of 10.16 mm which weighs a total of 2.2 kg (Figure 8). The casing of the tether allows for easier handling and storage which will reduce wear and tear on the cables. The tether has two 14 AWG power cables, one Category 6 Ethernet (CAT6) cable, one air pipe, and a closed cell neoprene foam. The one 12-5V DC-DC step down regulator on ADAM ROV has an operating input of 6V to 40V. To establish a safety margin, a 25% to 30% voltage drop (Vdrop) under maximum load of 25 Amps (A) was considered acceptable for the power system. With the tether length being 20m, a 25% Vdrop corresponds to a resistance per length value of 3.3 mΩ/meter and 30% Vdrop corresponds to 3.6 mΩ/meter. These match the resistance AWG value of around 10 to 11 respectively in which the 10 AWG was chosen for the lowest possible Vdrop without compromising flexibility. The single CAT6 cable is used to establish an Ethernet connection between the onboard Raspberry Pi and a computer inside the on-shore computer. The air pipe is used to supply and exhaust the air to and from the lift bag using an on-shore air compressor. Additionally, the closed cell neoprene foam is utilized for achieving neutral buoyancy of the tether in any depth due to the air pockets in the foam not being able to collapse to create positive buoyancy. Apart from the first version of the tether, which had 10 AWG power cables and a much larger air tube, the current version allows for more flexibility to minimize hinderancing the maneuverability of ADAM ROV.

Control Box

The design rationale behind the control box was to create the simplistic and compact command center for ADAM ROV's operation. The control box has limited wiring and electronic components such as motor controllers, power busses, and logic boards due to the ADAM ROV design of housing majority of the electronics device within its frame. The control box contains the computer, ROV power cable, voltage/amperage sensor, and a single pole single throw (SPST) "kill switch". The "kill switch" is placed on the control box's bottom plate to allow for quick disconnect of power to ROV if any safety concerns arise. The four main components of the control box are the top plate, bottom plate, excess wire holder, and computer bracket. The top and bottom plates were cut from sheets of high density polyethylene (HDPE) which are utilized to mount the computer and joysticks. The excess wire holder is a wooden box that acts as a container to hold the ROV power cable that is extended from the control box to the DC power supply. The HDPE was choosing for the building material due to the ease of manufacturing and tensile strength which would be needed in creating a custom panel and withstanding the weight of the computer system. The wood in the box acted as mounts for the panels to attach to which would make for better and lighter support than aluminum or steel.

3) Software

ADAM ROV's control system utilizes a surface laptop computer and an onboard Raspberry Pi 3 Model B SBC for communication, data collection, and ROV control (Figure 9). The Raspberry Pi was selected over other competing SBCs due to the overall computing power provided by the Quad Cortex A53 CPU and availability of established software drivers. The communication between the surface command center's computer and the ROV occurs using a CAT6 Ethernet connection and Internet Protocol (IP). By developing the on surface center software in a Linux operating system, it allowed for improved collaboration in software development and ease of component integration in the system. ADAM ROV's on board computer operates in Python software which enables vast online resources such as libraries and drivers to provide rapid prototyping abilities. DART used online cloud server applications such as GitHub for online collaboration, software validation, and data storage.

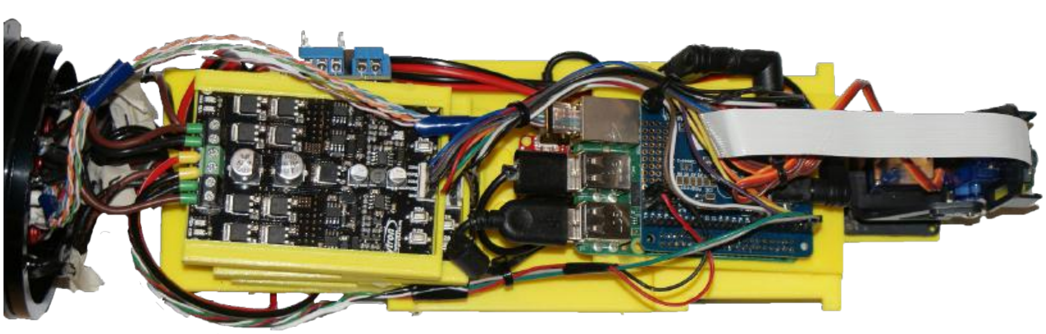


Figure 9: Interconnection of Raspberry Pi with ROV System

Network Protocol

DART's software system was developed through several stages, but the initial stage was to design the network protocol (the communication between the surface command center and ADAM ROV). The network protocol essentially breakdowns into two main components: response and request. The response component entails various commands but the most pertinent is the "Do" command which controls the ROV's movements, servos, and cameras. Whereas the request components capture the data specified by the software from the sensors and thrusters to receive feedback of the ROV's status.

Modules

DART has architected its software for ADAM ROV in such a way that it allows the program to be divided up into modules. This allows for easily debuggable, organized code with few dependencies. The program is split into networking, business, and controller modules. Using a client-server model, the networking module receives instructions from the dashboard, and sends messages to let the operator know the status of the system (Figure 10). This module then unpacks these messages and sends them to the business module. The business module takes the command it received and sends it to the controller module where it will be carried out. Any information returned by these commands is collected by the business module, where it can then be packaged up and set onto the networking module. The controller module is a set of classes that execute commands. When a certain command from the business module is executed, the corresponding controller will be activated to handle the request. This controller then calls upon the appropriate drivers which will interact directly with the hardware. Each module in this architecture is able extend their features, such as adding more controllers and commands, without affecting another module.

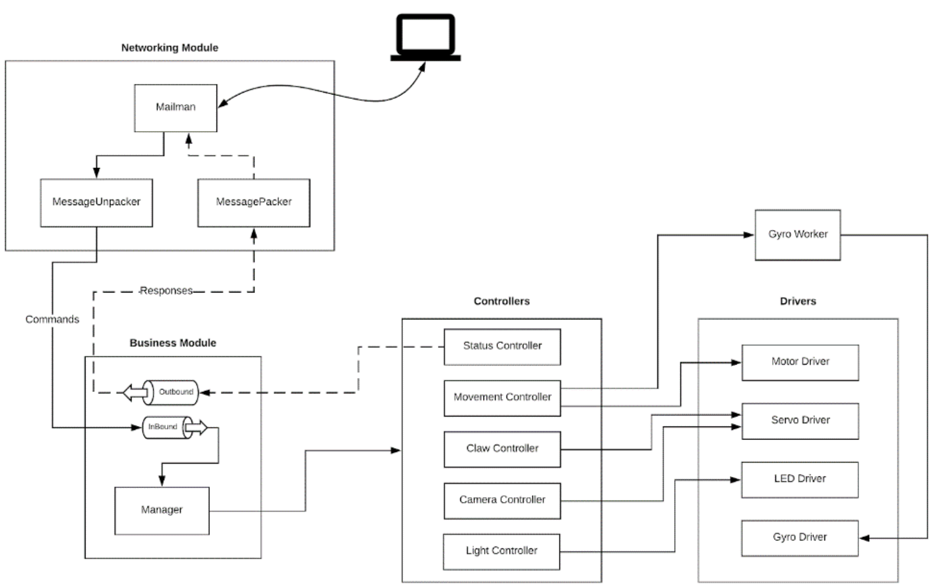


Figure 10: ADAM ROV's Software Architecture

Command Pattern

DART has taken advantage of common industry level software design patterns and incorporated it into the software system for streamlined communication and better solutions for commonly occurring issues such as parametrization and optimization. Software design pattern is a general solution to a commonly occurring problem in which the developer can apply various options to solve an issue. For example, DART leveraged one pattern to enable abstract defined instructions for the ROV as a command (Figure 11). Each command has its own corresponding controller which knows how to carry out the request meaning the business module won't need to know how to interact with speed controllers or servos, but rely on the fact that there is a controller who is responsible for this. During run-time, commands are placed in a queue so that actions are carried out chronologically. This helps to synchronize the flow of messages between modules and ensures that two conflicting commands are not executed at the same time. The flexibility of the command pattern also enables the ability to implement long running commands. These let the ROV carry out long running tasks, such as slowly closing the claw, or fading the LEDs over a period of time. These commands are executed on their own thread, to isolate them from the standard command execution.

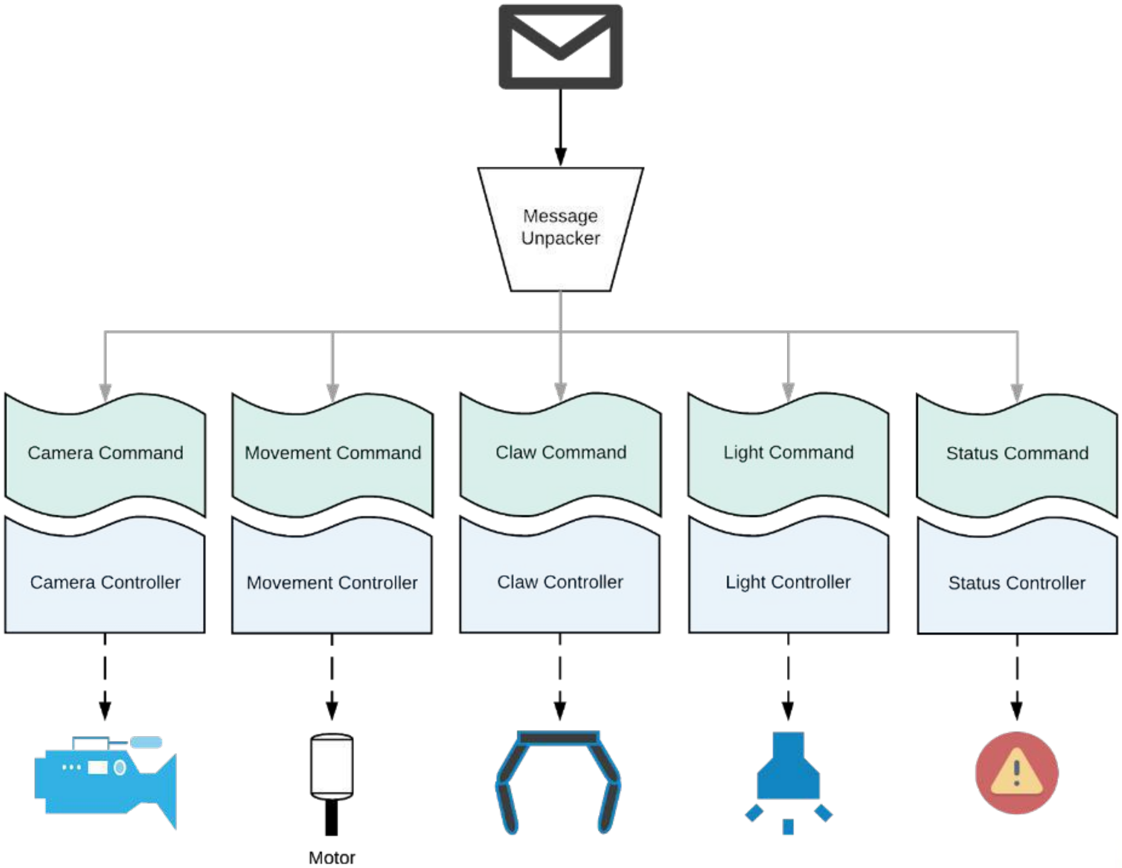


Figure 11: Execution Procedure of Each Component on the ROV

Semi-Autonomous Functionality

ADAM ROV employs an inertial measurement unit (IMU) sensor and a pressure sensor to enable semi-autonomous functions. As one of the toughest tasks in piloting an ROV is to maintain a heading or direction due to external factors such as drag force and tidal currents. The IMU consists of a gyroscope, accelerometer, and a magnetometer which integrated into the software system can allow the ROV assist and hold position features. The software for these features are designed in a command drive fashion which maintain its current "state" or position until a command is received that instructs it to do otherwise. To maintain position, current orientation and velocity feedback is given by the gyroscope in the means of angular acceleration. The data from the gyroscope can be integrated over time to find out our angular velocity and heading in degrees. By using the angular velocity and heading in degrees, ADAM ROV can detect minute changes in the three axis orientations in which the ROV will automatically adjust to the desired heading or direction and eliminate any drift in any other direction. The pressure sensor can convert the change in pressure from a set point to change in depth in meters in which will allow for set dive depth. ADAM ROV can be set to dive a specific depth by using the data from the sensor which will greatly help to reduce the role of the pilot when diving.

Dashboard

DART's software division developed a user friendly graphical user interface (GUI), or dashboard, that is responsible for processing input from both the pilot and co-pilot and distributing the output to the ROV thrusters, sensors, and servos (Figure 12). The GUI displays the systems diagnostic and sensor data while presenting telemetry data and video feed. The dashboard is written in Microsoft C# running on .Net 4.6. To handle the actual display of data and video from the ROV, MonoGame (a port of Microsoft XNA) software was implemented to give various methods of interfacing with the Xbox gamepads and a way to draw to the screen, as well as many utilities to perform vector calculus. To ensure ADAM ROV does not go above the maximum allowed current, a current and amp sensor is installed within the control box which is read by an Arduino and sent to the dashboard. This allows the ability to monitor the power consumption and detect any unusual power spikes that could indicate a problem or blow the inline fuse.

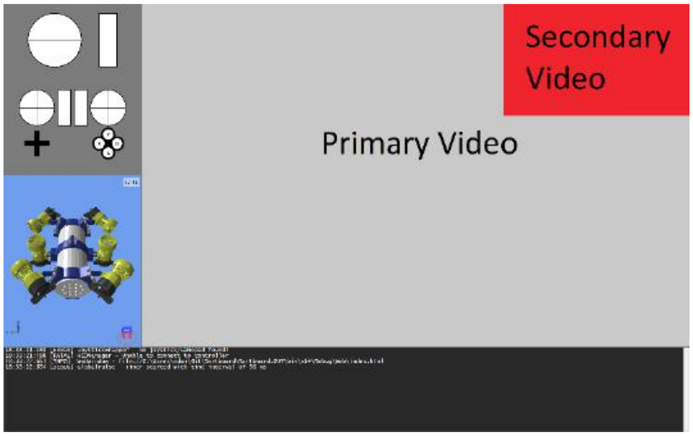


Figure 12: ADAM ROV Dashboard with Control and Vector Feedback

C. Mission Specific Features

Manipulator

ADAM ROV is equipped with a manipulator mechanism designed and developed in-house. It is oriented vertically to accomplish several tasks such as lifting the debris/engine, disconnecting the OBS cable connector, installing tidal turbine, collecting samples of eelgrass, and transporting I-AMP. The design of the manipulator revolved around two main concepts: task achievability and modularity. The components of the manipulator were 3D printed from PLA, which allowed for easy integration of a modular design into the mounting clamps (Figure 13). An array of M3 holes were designed for modularity through the ability to rotate positions and adjust the maximum opening of the manipulator. By introducing a three-component pincher, it allowed for improved collection methods compared to a single pivot point creating more load on the micro-servo. Additionally, one of the two pinchers is fixed at a point to decrease load on the servo and permit more weight to be applied to the manipulator. An arm was developed to connect to the manipulator which would enable the pilot to have direct line of sight of the target or task. The manipulator adopts a vertically clamping mechanism where a micro-servo moving a pincher section opens against the fixed section up to 3.175 cm. This is an abundant amount of space for the pilot to pick up large objects easily.

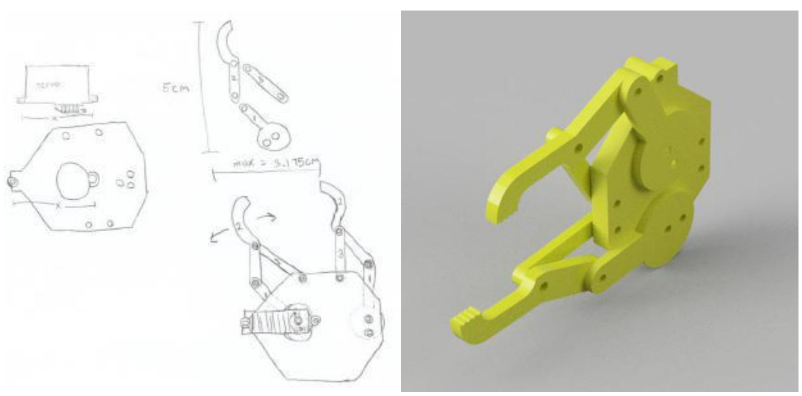


Figure 13: Initial Concept to Final 3-D Rending of the Manipulator

Acoustic Doppler Velocimeter (ADV)

Figure 14: ADV Consist of Ballast, U Bolt, and Hook

The Acoustic Doppler Velocimeter (ADV) was designed to attach to the mooring device at a given height from the lowest point. The design encompassed a hook into the ADV which will allow ADAM ROV to attach to the U-bolt on the mooring line (Figure 14). The hook was 3D printed in PLA and connected to a mini enclosed ballast filled with air allowing the ADV to float when attached to the mooring device. A U-bolt was incorporated into the design allowing the ROV to easily attach and handle the ADV in transportation and completion of the task.

Wreckage Zone/Maximum Power Generation GUI

For the two tasks of searching for the wreckage zone and calculating the maximum power generation for a tidal turbine, a graphical user interface (GUI) was developed to allow for quick and error free calculations (Figure 15). The GUI was developed in Python using the Tkinter library to create an interface that would enable the user to input the given data to get an output of the direction vectors and the maximum generated power. Behind the GUI, the inputted data is inserted into predetermined single function equations in which will return the appropriate results to the GUI.

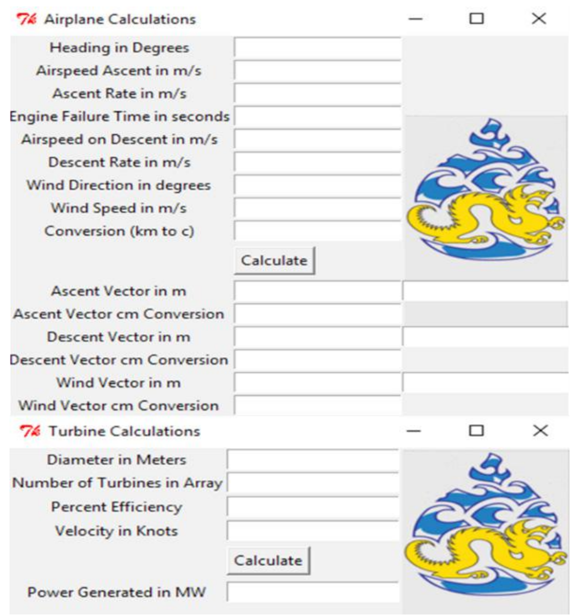


Figure 15: GUI Interface for Vector/Power Calculations

Lift Bag

To remove the debris and return the engine to the surface, the mechanical division researched and designed a closed buoyancy assisted lift bag. The lift bag consisted of 0.45 m diameter latex balloon attached to a NPT and barrel connector, allowing air tubing to be connected, inflating the lift bag (Figure 16). The specific diameter of the balloon was chosen in respect to the lift force needed to lift the debris and engine. The lift bag is installed with a double-sided hook device that enables a U-bolt grabbing point for the ROV when attaching the lift bag to the debris or engine. The air tubing is supplied on the surface through an air compressor with a three-way ball valve to release the air in the lift bag when moving to another task. The tubing was integrated in the ROV's tether through a disconnect point where upon task competition the lift bag will be detached and the tube to be capped.

Figure 16: Lift Bag with U-Bolt Attachment for ROV Control

Ocean Bottom Seismometer (OBS)

The Ocean Bottom Seismometer (OBS) system consists of a three-tier system: OBS unit (cable connector cradle), release mechanism, and anchor. The cable connector cradle is a 36.75 cm length by 26 cm width by 25 cm in height rectangular box with an open top face for the placement of the cable connector. The cradle dimensions allow ease of placement of the cable connector and provide sufficient buoyancy to float to the surface when released by the acoustic release mechanism. The cable connector cradle is connected to the release mechanism via a 3D printed U-bolt plate with an integrated ferrite/neodymium magnet which attaches to the electromagnet outside of the release mechanism housing. The release mechanism is housed in a waterproof diver case, and on top of box aretwo 10mm BlueRobotics penetrators for electrical power and acoustic data collection via a microphone senor. To trigger the OBS, a 3000 Hz pulsed tone produced by a piezo buzzer on the ROV must be acquired by the microphone. The on-board Arduino Uno will approximate the principal frequency of the sound at a particular instant using the Fourier Transform, which is valid for three 1.5 second periods in a row of the signal played continuously to trigger the release of the OBS (Figure 17). Once triggered, the two relays will flip to induce an opposite electromagnet field by inverting the polarity of an electromagnet. Thus, releasing the ferrite/neodymium magnet from the release mechanism will cause the cable connector cradle to float to the surface. The release mechanism has a 3D printed U-bolt plate attached to the bottom of the diver's case and connected to the 1.7 kg anchor holding the entire OBS system in place under water.

Figure 17: OBS Release Mechanism Internal Schematic

III. SAFETY

A. Safety Philosophy

DART's highest priority is safety. We believe accidents can be prevented with the use of proper safety training and measures. Numerous safety protocols are enforced during every team meeting, guaranteeing the safety of the employees, ROV, and the environment. During each team meeting, a safety review is held to address a new topic of possible injury or harm that can be caused either inside the work environment or outside in the field.

B. Vehicle Safety Features

Figure 18: SPX 1250 GPH Bilge Pump with Safety Sticker

Safety is integrated to the vehicle design and considered throughout ADAM ROV's development (Figure 18). The mechanical engineering division ensured the absence of sharp edges on ADAM ROV by rounding in the 3D model and coating each element on the ROV with a rubber coating. The body of the frame has open space for crew members to safely transport the ROV using rubber coat gloves. DART incorporates a custom IP-20 mesh guard to encapsulate the thrusters protecting against any type of marine life and human harm. The electrical engineering division installed a kill switch between the 12V power supply and the tether and an inline fuse on the positive lead of the power supply to ensure the ROV can be shut down in the case of an emergency. Moreover, the interior body of ADAM ROV has LED status indicators to visually check the progress or issues before, during, and after operation. All the electronic components within the ROV are insulated connectors from ring terminals to ferrule to ensure proper connections and reduce the possibility of a short circuit. The software division programmed the voltage and amperage sensor to detect any spikes and abnormalities to alert the pilot of any issues with the ROV.

C. Testing Protocol

DART has established a strict testing protocol to ensure operational and environmental safety. Before testing ADAM ROV underwater, the on-deck staff must perform a systematic dry test since unanticipated problems are easier to resolve in air than underwater. A safety checklist was established by the company to be followed by all employees in launching, operating, and retrieving process (Appendix B). For example, the on-deck staff are not allowed to touch ADAM ROV unless the ROV is idle after completing the launching protocol. Following this process, injuries can be prevented by not allowing accidental activation of the thrusters and manipulator. In an emergency situation, any of the on-deck staff closest to the power supply must immediately cut off the power to avoid injury to the staff and the operating environment.

D. Testing and Troubleshooting Techniques

DART runs weekly tests of the ADAM ROV in water to assess its performance and stability for possible improvements. The vehicle underwent its first water test in late January 2018 and was initially tested in a 4 m deep pool for vehicle core functions such as movement, cameras, and buoyancy. After the core functions were established, the company proceeded to a two-hour pool test to evaluate ADAM ROV's performance in completing missions. Any unforeseen shortcomings in the design phase are discovered and we brainstorm ideas to address the issue. Throughout the testing periods, the 3-D printed parts fill density was constantly changed to understand the optimal fill for structural support and weight. For example, the ROV was increasing in negative buoyancy as more time was spent operating the vehicle in a single test. It was discovered that the 3D printed parts were holding water between the layers of the 3D printed material causing a slow leakage of water to fill the components. Henceforth, each 3D printed material was coated in a synthetic rubber coating to seal the parts and not allowing any water fill into the pieces.

DART's approach to troubleshooting is to apply a root cause analysis (RCA) method, an industry standard process that involves isolating, diagnosing, and preventing the problem. Problems are usually discovered during or after a water test and engineers will begin to isolate the problem in the laboratory for validity. Each component is diagnosed for the problem and thoroughly tested before being eliminated as a possible source of error. Once the problem is recognized, the problematic module will be either resolved by redesigning or monitored during operation to avoid triggering the issue.

E. Work Environment Safety Practices

All employees of DART are required to receive safety training and follow safety protocols while working in the laboratory. To ensure cooperation with all employees, waivers are signed to ensure all safety requirements are followed. Personal protective equipment (PPE) is made available at all machining and soldering stations including safety goggles, ear plugs, and respiratory masks. As part of the PPE, all employees in the laboratory or the field are required to wear rubber grip gloves, long pants, and closed toed shoes. DART requires a buddy system in the laboratory space for the safety and protection of the employee so any dangers can be reduced or help can be provided quickly if issues occur. Each machine and tool designated as potentially harmful, such as drill press, band saw, and or soldering stations, have a checklist protocol that must be completed and signed off after each use to ensure safety practices are followed. At DART, every employee is encouraged to help each other when unsafe practices are noticed to guarantee the safety of all. The employees are encouraged to proactively update the safety protocol when better practices or a dangerous situation arises to prevent the same injury in the future.

IV. PROJECT MANAGEMENT

A. Organization, Structure, Planning, and Procedures

DART promotes cross-disciplinary collaboration and open mindedness as a company culture. The organization of the company is a flat structure which day-to-day operations are self-managed within each division in the organization. The company is divided into four divisions: mechanical, electrical, software, and marketing which enables efficient work flow from the initial concept to the marketing platform. The company holds bi-weekly meetings to communicate goals throughout the company and update the Gantt chart to keep track of the timeline. Each division sets weekly goals in addition to discussing and resolving any obstacles with the development of the ROV. During the development of the ROV, 3D designs and simulations occurred throughout of development of any part to reduce the waste of resources such as 3D filament and plastic sheeting. However, the final decision is a collective input from the company as a whole to ensure all options are discussed, creating the best possible outcome.

During DART's first year in operation, many employees were not involved in underwater robotics field compared to other member who have more experience in the underwater robotics environment. The integration of experienced and inexperienced divisions was critical in fostering a mentoring and collaborative environment. This type of environment fosters rapid integration, leading to a thorough understanding of underwater robotics concepts and development process of an ROV. The Gantt chart was used as a tool to understand the priorities of the company that needs to be addressed (Appendix B). In addition to the Gantt chart, an online scheduling tool was used in conjunction to complete day to day tasks and problems. The online scheduling tool was through Google Calendar in which DART's CEO and division leads would establish weekly tasks/problem to be completed by a certain deadline following the Gantt chart timeline. If issues arise where the deadline is not met, the entire company will have a meeting regarding the problem and discuss the adjustment to the Gantt chart and Google Calendar timeline. By having all the company staff at the meeting, it ensures the entire company is aware of the issue and can be mitigated or eliminated the next time.

DART is comprised of four divisions: mechanical, electrical, software, and marketing which ensures proper engineering principles and business strategies are followed from the initial concept to the final product. The mechanical consisted of four employees who used various technical resource to research and develop hydrodynamic models to identify the optimal frame design that reduces the frictional force or drag on the ROV. Another task mechanical division was asked to design and manufacture a manipulator, lift bag, OBS, and ADV required by the APL at University of Washington request for proposal. The electrical division was responsible for the configuration of all the on board electronics which included in single board computer (SBC) and thruster controller selection. Also the electrical division designed and wired the power distribution system from the control box through the tether to the ROV. The software division responsibilities entailed in developing a custom dashboard and software program which integrates all the ROV's sensors to assist the pilot through semi-autonomous facilities to increase performance. Finally, the marketing division assist the organization to make business decisions in marketing pitch, ROV material selection, and all associated paperwork.

B. Budget and Cost Projection

We developed the budget for ADAM ROV first by understanding what was required of the ROV to complete the tasks (Appendix C). As a newly established company, a large sum of funds went toward the mechanical and electrical division, buying new components since no previous resources were available. The company understood that the success of the robot would come from the mechanical and electrical integrity of the ROV. Meticulously selecting parts and allocating the appropriate funds toward the components meant that the company would be able to reuse some of parts in the future. For the software division, a smaller sum of the budget was apportioned due to open source code, and low cost commercial hardware that can be integrated into the ROV. All sources of income came from

Drexel University, in order for us to buy new tools, parts for the robot, 3D printing material/printer, and to be able to travel.

V. CHALLENGES

A. Non-Technical Challenges

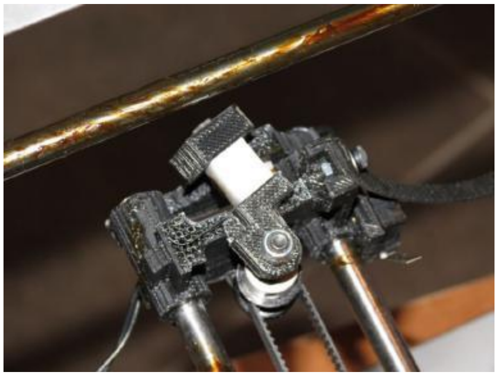


Figure 19: Third Incident of a Broken 3D Printer Nozzle

This is DART's first year in operation, and the company relied heavily on rapid prototyping with a low cost by using the 3D printing resources donated by Drexel University. However, the company was faced with the logistical aspect of changing locations and offline issues of 3D printers. The company would make a printing request, only to have it bounced around several departments until it could be completed or denied because of machine maintenance (Figure 19). This would cause large delays in the requested date to the actual pick up date, leading to major changes in the testing timeline. This problem was alleviated by identifying an offsite 3D printer that was available before the requested day for pick up. Team work and communication ensured that all 3D components thereafter were printed on time with high accuracy. Another organizational challenge was attendance for all employees since some are part-time. Not having all employees present every day allowed for the possibility of miscommunication and a decrease in production. To avoid this, weekly departmental meetings were held after work hours, so that all employees were kept up to date.

B. Technical Challenges

One challenge that DART faced was perfecting the release mechanism of the Ocean Bottom Seismometer (OBS). The release mechanism of the OBS involves an acoustic selective release mechanism. ADAM ROV's buzzer would play three consecutive 3000 Hz pulse signals must register in the OBS microphone sense to release it. Once the microphone sensor registers the signal, two relays are triggered to inverse the electromagnet, causing an inverse in the electromagnetic field, repealing the ferrite/neodymium magnet combination to release the OBS. Although the software of the OBS was consistent in detecting the acoustic signals, when testing with a neodymium magnet, the OBS release mechanism would cause false positives due to the large electromagnetic field flip associated with the stronger magnet. After further research into magnetic fields and electronics, it was noted that most modern electronics are made with magnetic material so the disturbance of the field or field inverse would short out the processor. This means that the combination of the electromagnet and neodymium would cause the microcontroller to restart because the energy of the field change was too sudden for it to adjust. Through further research and experimentation, the solution of using a combination magnet and separation plate between the magnet and OBS release mechanism was chosen to reduce the magnetic field change. By testing the design of the combination ferrite and neodymium magnet, it was concluded that using 3.175 mm plate in-between two neodymium magnets on the top and a single ferrite magnet at the bottom to achieve the results need to accomplish the task.

VI. LESSONS LEARNED

Figure 20: Louie (In front of Dill Press) Demonstrating the Proper Use of the Drill Press to Arjun

Mentoring

This year, there was a strong focus on peer to peer mentoring as many members from the team were new to the underwater robotics while some had background knowledge from previous robotics competitions. It was critical to ensure all new members were trained and taught in the various technical skills and safety awareness needed to design, develop, and operation an ROV. The mechanical division learned how to use laboratory tools to ensure safety of members and the lifespan of the tools. More advance lessons taught to reduce waste material and ease of assembly options to better the mechanical design (Figure 20). The electrical division learned the electronic theory to get accustomed with digital sensors and power distribution systems. The software division was familiar with C Sharp so their software was reviewed and tested early in the design process. The team spent a considerable amount of time together, growing together in their knowledge, confidence, and passion for underwater robotics technologies which help with communication and voicing their opinions.

Interpersonal

The team spent a considerable amount of time together, growing together in their knowledge, confidence, and passion for underwater robotics technologies. The focus on mentoring created an environment where all employees were comfortable with asking questions and depending on coworkers for help when they needed it. This open, judgement-free environment allowed for this knowledge to be shared and also increased employees communication skills. There were some employees who tended to be reserved when DART first started, but as the year progressed, their confidence grew and they became more comfortable with voicing their opinions. It was rewarding to watch employees improve both their soft and hard skills throughout the year.

Integration of Sensors

The introduction of sensors in DART deepened the company's knowledge on sensor application to automate various processes. By utilizing the gyroscope, accelerator, and pressure sensors, it is was possible to design a pilot assist function for operating the ROV. These sensors allow live feedback into the software to adjust maximum propulsion and reach set locations. Learning how to operate the sensors was quick as it only required users to power and communicate via microcontroller to receive the feedback data. The challenge with the sensors was the translation and filtering of data to find crucial values to communicate with and assist the ROV in its tasks. By including more sensors into the design, it allows for the growth of the electrical and software divisions experience in designing autonomous systems which can be applied to almost any situation or environment.

VII. Future Improvements

<u>3D Layered Printing</u>

In the past year, DART has been using 3D printing as a main source of manufacturing for all structural and functional components of the ROV. The PLA material used in the 3D printing was an excellent option for the cost versus tensile strength, but the material absorbed water into the layers of printing. The water absorption would vary depending on the time it was submerged underwater, which would cause issues in buoyancy as time elapsed. DART corrected this issue by coating the material with a synthetic rubber. While this did solve the issue of water absorbing into the material, it caused overwhelming delays in the cost, time, and complexity of the 3D printing and an increase in manufacturing costs. In the future, improving the design of the printed objects and changing the 3D printer parameters such as nozzle size and fill, the 3D printed components would be more easily waterproofed. Despite this, DART engineers still strive to improve the present design from previous developments.

VIII. Reflections

“Becoming DART’s first Vice President and joining the software team has allowed me to make countless amounts of memories and develop various new skills. Stepping into a leadership position, especially in this team’s first year, was definitely a challenge at first. Along with my other board members, we not only had to focus on creating a functional robot, but also on building a team strong enough to compete and succeed in competition. Working on the software for the ROV has taken what I already know about programming and advanced it to another level. While learning computer science and software engineering skills in class, I was able to apply them through the software team’s work, which ranged from designing efficient and robust software to applying theory. Being a part of this team has taught me not only underwater robotics, but also what it is to be a part of a development team, from both a leadership and technical role. Solving the problems we have experienced, whether it was legislative or technical, made being a part of this team more and more rewarding as we tackled them head on.” – *Jose Arguelles*

“Joining DART has been a great decision. From the verybeginning, I could start chipping away at our goal of creating a ROV. Being a part of the electrical division has given quite an insight as to how to efficiently power the entire vehicle without a drop-in power from the start of the tether to the ROV. It has enhanced my problem-solving skills by aiding in finding leaks in the electronic enclosure and helped with creating neutrally buoyant tether from scratch through theoretical calculations. I was even able to gain mechanical engineering and computer programming skills, as well as project management skills, by being able to freely collaborate between all the disciplinary teams. I look forward to continuing to learn with the team for the rest of my college career!” – *Arjun Pillai*

IX. ACKNOWLEDGMENTS

Sponsors

Special Thanks To:

Drexel University's Interim Dean of College of Engineering Giuseppe Palmese – for providing sponsorship and labs for DART use.

Drexel University Recreation Center – for allowing DART to use the dive well for testing ADAM ROV

Stephanie Delaney – our advisor, whose guidance and advice helped us improve both our technical and non-technical skills.

Kyle Juretus – for the support and guidance with any technical and logistical issues

Jonah Levin – for providing assistance with imaging processing and editing

MATE Center – for organizing the international competition, providing a platform for the growth of entire community, and promoting STEM education around the world.

SPX Inc. – for donating SPX bilge pumps for ADAM ROV

Autodesk – for sponsoring Fusion 360 Student Edition CAD software for DART

Jane White – for assisting in any issues regarding MATE ROV competition preparation

Velda Morris – for guiding and organizing the Pennsylvania Regional MATE ROV Competition 2018

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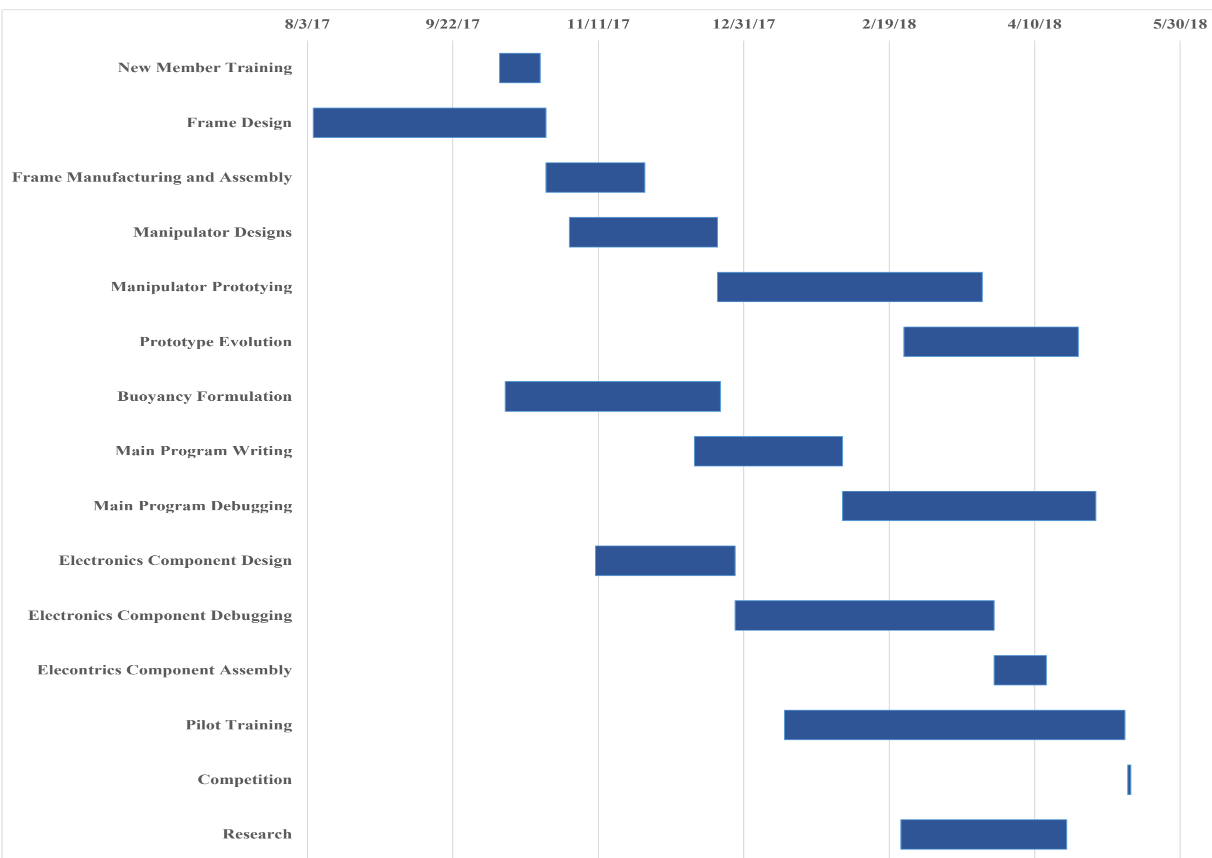
XI. APPENDICES

Appendix A: Gantt Chart



Appendix B: Operational Checklist

Pre-Power:
☐ Clear the area of any debris/obstructions
☐ Check to see if power supply is "OFF"
☐ Connect Anderson connectors to tether to power the supply
☐ CHECK ROV
    ☐ Check Claw and OBS Mechanism
    ☐ Check Electronics Tube and Bus Bars

Power Up:
☐ Pilot boots up the Laptop
☐ Pilot calls team to their attention
☐ Co-Pilot calls out, "Power On" and moves power supply to "ON" position.
☐ SHORESIDE team checks to see if ROV is on by checking electronic status lights.
☐ SHORESIDE puts ROV underwater under control and makes sure it remains stationary. When ROV is ready they call out "ROV is Ready"
☐ Pilot takes control of ROV and performs thruster test.
☐ The SHORESIDE team puts ROV underwater under control and makes sure it remains stationary.
☐ If no issues found, continue to Launch Procedures.

Launch:
☐ Pilot calls for Launch of ROV and starts timer
☐ SHORESIDE team lets go of ROV and calls out "ROV Released"
☐ Mission tasks are commenced

Bubble Check:
☐ If bubbles are spotted during mission, pilot re surfaces the ROV
☐ Co-Pilot calls out "Power Off" and turns off the power to the ROV
☐ SHORESIDE team retrieves the ROV
☐ If after trouble shooting time remains continue to Power Up Procedures.

Loss of Communication:
☐ Co-Pilot checks the tether and laptop connection on the surface
☐ Pilot attempts to reset the program controlling the ROV
☐ Co-Pilot cycles through the power supply
☐ If any of these steps restarts communication, continue mission.
☐ If all these steps fail, the mission stops, the co-pilot turns off power and calls out "Power off"
☐ SHORESIDE team retrieves the ROV

ROV Retrieval:
☐ Pilot signals for ROV retrieval to SHORESIDE team
☐ SHORESIDE team member puts arms in water up to the elbows and retrieves ROV once contact is made with ROV.
☐ SHORESIDE team yells, "ROV retrieved" and pilot stops timer.

Demobilization:
☐ Co-pilot turns power supply off and calls out "POWER off"
☐ SHORESIDE team inspects ROV for any dam ages or leaks that might have occurred during the mission.
☐ Pilot stops program controlling the ROV and powers off the laptop.
☐ Anderson connectors from the tether are dis connects and removed from the power supply.
☐ Cameras and monitors are turned off.
☐ Team makes sure area is clean and then vacates the area.

Appendix C: Budget

Travel Expenses		ADAM ROV Development		Sponsorships	
Airfare (14 members)	$ 7,700.00	Electrical Components	$604.85	Parts and Materials (Drexel College of Engineering)	$ 1,600.00
Hotel (4 Nights, 7 Rooms)	$ 4,172.00	Mechanical Components	$777.94	Registrion Fees (Drexel Student Organization Fund)	$ 500.00
Rental Van	$ 225.00	Software Components	$176.30	Airfare (Drexel Electrical Engineering Department)	$ 5,000.00
Total	**$ 12,097.00**	**Total**	**$1,559.09**	**Total**	**$ 7,100.00**

Appendix D: Cost Projection

Type	Item	Market Price (USD)
Electronic Components		
Purchased	ATC/ATO Inline Fuse Holder	$5.18
Purchased	2.1mm Straight DC Coaxial Power Plug to Powerpole Adapter 6 ft.	$15.98
Purchased	30 Amp Toggle Switch SPST On-Off	$15.95
Purchased	Raspberry Pi Camera Module V2 - 8 Megapixel,1080p	$29.45
Purchased	JacobsParts DC Barrel Jack	$3.95
Purchased	Pololu 5V, 15A Step-Down Voltage Regulator	$39.95
Purchased	Adafruit NeoPixel Digital RGBW LED Strip	$17.95
Purchased	Missile Switch Cover - Red	$1.95
Purchased	Blue Sea Systems DualBus Plus 150A BusBar - 1/4	$23.73
Purchased	22" Black Tactical Weatherproof Equipment Case	$59.99
Purchased	102VNTCX5000MCR 10 AWG /2 Conductors	$81.00
Purchased	10-CONDUCTOR SHIELDED CABLE W/ DRAIN	$6.20
Purchased	3/4" PET Expandable Braided Sleeving - 25Ft (Yellow)	$40.77
Purchased	Uxcell Electomagnet	$15.54
Purchased	Marine Epoxy	$18.00
Purchased	Shapenty White Plastic Film Canister Holder	$7.90
Purchased	Electret Microphone Amplifier - MAX4466 with Adjustable Gain	$6.95
Purchased	45 Amp Unassembled Red/Black Anderson Powerpole Connectors	$36.99
Purchased	Lucas Oil 10682 Marine Grease - 3 oz (Pack of 3)	$9.76
Purchased	DEDC 480Pcs Insulated Wiring Terminals Wire Connectors Assortment Electrical Crimp Terminals Kit	$15.38
Purchased	Xbox One Remote	$42.95
Purchased	Dual Channel 10A DC Motor Driver	$74.34
Purchased	Logitech 963290-0403 Extreme 3D Pro Joystick	$34.99
	Electronics Sub-Total	**$604.85**
Mechanical Components		
Purchased	ATP IMBIBE NSF 61 Polyethylene Plastic Tubing	$18.23
Purchased	Waterproof Micro 180° Rotation Servo	$27.99
Purchased	Watertight Enclosure for Electronics	$215.00
Purchased	Cable Penetrator for 8mm Cable	$52.50
Purchased	Mini Pan-Tilt Kit - Assembled with Micro Servos	$18.95
Purchased	316 Stainless Steel Hex Head Screw	$7.99
Purchased	18-8 Stainless Steel Socket Head Screw	$12.13
Purchased	HATCHBOX PLA 3D Printer Filament, Dimensional Accuracy +/- 0.03 mm, 1 kg Spool, 1.75 mm, Black	$22.99
Purchased	HATCHBOX PLA 3D Printer Filament, Dimensional Accuracy +/- 0.03 mm, 1 kg Spool, 1.75 mm, Blue	$28.00
Purchased	18-8 Stainless Steel Hex Nut M3	$5.36
Purchased	18-8 Stainless Steel Socket Head Screw M8 x 1.25 mm Thread, 10 mm	$14.10
Purchased	Sanatec High Density Polyethylene Sheet, Matte Finish, 1/4" Thick, 36" Length x 36" Width, Blue	$33.40
Purchased	Sanatec High Density Polyethylene Sheet, Matte Finish, 1/4" Thick, 24" Length x 36" Width, Yellow	$24.98
Parts Donated	SPX 1250 GPH Motor Cartridge	$239.94
Purchased	3D Printing Service	$56.38
	Mechanical Sub-Total	**$777.94**
Software Components		
Purchased	Raspberry PI 3 Model B A1.2GHz 64-bit quad-core ARMv8 CPU, 1GB RAM	$35.70
Purchased	9DoF Razor IMU M0	$49.95
Purchased	16-Channel Servo Hat for Raspberry Pi	$17.50
Purchased	SanDisk Ultra 32GB microSDHC UHS-I Card with Adapter	$16.90
Purchased	Arduino Uno R3 Microcontroller A000066	$19.99
Purchased	Tolako 5v Relay Module for Arduino	$5.80
Purchased	RJ45 Gold Plating Connectors	$6.99
Purchased	Cat6 Stranded UTP Ethernet Cable	$15.49
Purchased	LED Controller	$7.89
	Software Sub-Total	**$176.21**
	ADAM ROV Cost	**$1,559.00**