Sea Rams

Technical Document

The Hill School, Pottstown, PA

Sea Rams

The Hill School

Pottstown, PA

Name	Position	Major or Intended Major
Aaron Lethers	Graphics Designer	Computer Engineer
Alan He	**Design Engineer**	**Electrical Engineer**
Alex Rakos	Graphics Designer	Pre-Law
Andy Donato	**Systems Interconnection Specialist**	**Computer Engineer**
Breana McDonald	Project Manager	Life Science
Ceylin Sener	**Communications Director**	**Not Declared**
David Park	**Robotic Arm Developer**	**Computer Science**
Dylan Spector	**Chief Technology Officer**	**Computer Engineer**
Erik Patrinostro	Ergonomics Design	Aerospace Engineer
Harrison Nicholls	Chief Financial Officer	Pilot (Military)
Harrison Wolf	Software Intern	Not Declared
Jake Trombley	Law & Relations Coordinator	International Relations
Kevin Kim	Chief Design Officer	Architectural Engineer
Manshu Sharma	**Chief Executive Officer**	**Economics**
Damian Baraty	***Team Captain***	***Biology***
Tim Jump	*Engineering & Technical Consultant*	*Art*
Rob Steinman	*Theoretical Physicist Consultant*	*Physics*

Bold indicates Advanced Team representing Sea Rams at MATE International Conference, June 22-26, 2016.

Table of Contents

I. Abstract

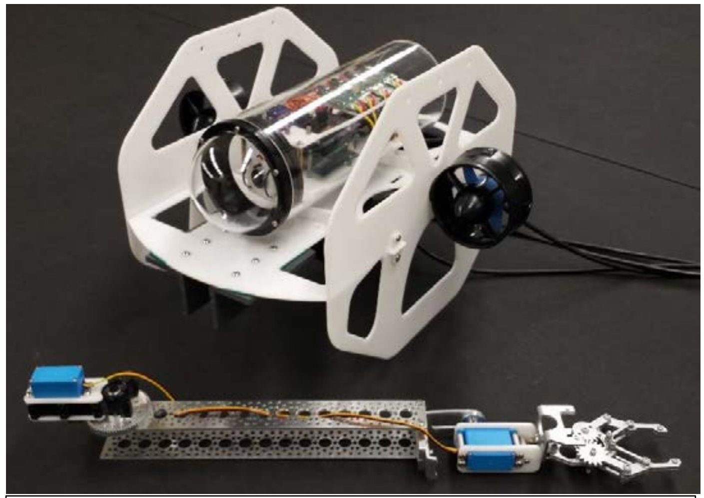
The Sea Rams designed *True*, our ROV, to perform in two demanding and hostile environments: in the frozen ocean of Europa and supporting missions in the Gulf of Mexico. NASA and Oceaneering Space Systems, supporting NASA's missions, require an ROV capable of withstanding the vacuum of space and the pressure and corrosion inducing ocean depths. We therefore designed *True* to be as modular and extensible as possible, following NASA's 1990's era approach to mission design thinking known as FBC: "Faster, Better, Cheaper." While designing to minimize cost, complexity, and size of *True* for affordability and easy interplanetary transport, we did not limit *True's* capabilities, allowing for any number of tools and/or parts to be easily replaced or fixed. Beyond its accessibility and capability, we also wanted *True* to be safe and easy to use. For that reason, *True*, programmed with custom software has multiple safeguards in place to ensure the safety of its users and the ROV itself. With the perfect balance between performance, efficiency, cost, and safety, *True* provides an affordable and capable solution for critical missions, here in the Gulf or orbiting Jupiter.

Figure 1. Team members (picture left to right): Harrison Wolf, Harry Nicholls, Manshu Sharma, Alan He, David Park, Jake Trombley, Alex Rakos, Aaron Lethers, Ceylin Sener, Breana McDonald, Kevin Kim, Erik Patrinostro, Dylan Spector (not pictured: Andy Donato). *Photo Credit: Wypkelien Steenhuis.

II. Design Rationale

Our mission: to create the most efficient, yet simple to use, ROV possible for use in exploring Europa or deployed to the Gulf of Mexico.

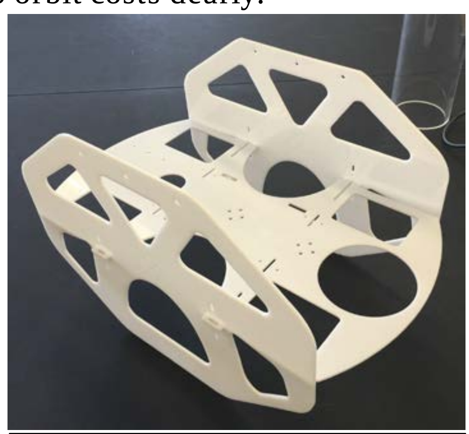
In the 1992, administrator Dan Goldin challenged NASA to design its exploration missions in a Faster, Better, Cheaper (FBC) mode in order for NASA to remain viable and credible moving forward. On July 4th, 1997, Mars Pathfinder touched down on the 4th planet and became a huge success, not only because the mission itself exceeded all expectations for longevity while it minimized cost, but because of the way in which it was designed, with a focus on smaller missions that incorporated advanced technology and a streamlined design process.



True ROV, assembled with pressure housing, electronics, thruster, and arm all visible. Photo by Ceylin Sener.

In the same vein, we started our design process by looking at the mission goals, specifically, the size and weight incentives for designing light and small. We designed *True* from the start to fit within a 48 cm circle, calculating the length of the vertical wing components and the curve of our base to conform to that circle. By designing in 3D in Solidworks, we virtually constructed multiple iterations of *True* without consuming a single sheet of plastic. Meeting this crucial size objective means that *True* can transport easily aboard an interplanetary spacecraft, where weight to launch into orbit costs dearly.

Another aspect of FBC design, incorporating proven technologies into the mission design process instead of redesigning from scratch, played out in the adoption of 3.175mm Delrin plastic, a super strong plastic from Dupont that we cut on our laser cutter. This plastic allows us to provide a strong frame with a minimal addition of mass to our robot, contributing 1423 grams to the craft's weight while providing just over 1000 cm^3 of displacement. Delrin flexes slightly in water, but remains stiff enough for the attachment of heavier components such as our thrusters. By securing the three larger plates together with a system of slots, tabs, and stainless steel screws, we can cut *True* from four sheets of 30.5 cm by 61 cm Delrin, and transport the frame folded flat in a briefcase if necessary.



True frame, naked, showing the assembly of Delrin panels. Photo by Ceylin Sener.

However, we considered the tether to be the starting point of the whole ROV. Possessing lengths of VideoRay donated tether featuring four power lines and six thinner data lines, we considered sending individual power lines to four motors, requiring eight wires. To support four motors, we would need to bundle two VideoRay tethers together. In a lighter ROV, this could prove to be unwieldy. So, to decrease the thickness of the tether to match a sub eleven kilogram ROV, we decided to send power and data signals down a thinner tether, and have a microcontroller send power to thrusters on board the ROV. Using the four tether power lines, we can bundle enough power to support the maximum 25 ampere current, although we have not found the need to draw that much power in practice.

While the power lines in the tether supports our energy needs on board *True*, we were not able to utilize the six data lines to sustain an Ethernet connection. Instead, we simply bundled a standard category 5e Ethernet cable along side the neutrally buoyant tether, and secured it within a sleeve that protects the tether from abrasions, cuts, and snags.

Once we decided to only send power and data to the ROV, we knew we required a pressure housing to protect the electronics on board the ROV. In accordance with FBC design practices, we researched and invested in a pressure housing manufactured by BlueRobotics, a trusted and acclaimed company specializing in marine robotics products. We also outfitted our ROV with four BlueRobotics T100 brushless motor thrusters. These motors offer the ROV a more powerful thrust to weight ratio than generic motors in an aesthetically pleasing housing that supplies mechanical mounts for attaching to our frame. We incorporated the mounting points in our 3D design in Solidworks, deciding on an orthogonal thruster layout after initial experiments with a vectored thrust ran into complications with the mounting of the vectored thrusters and our frame.

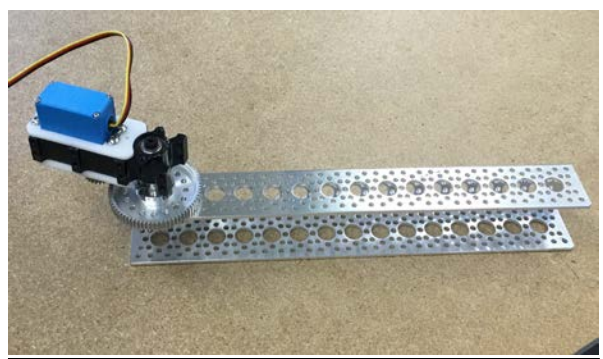
The thrusters account for a large portion of the weight of the robot, and the pressure housing provides buoyancy. Our current thruster load adds 885 grams to our ROV weight while adding 525 cm^3 of displacement, while the pressure housing adds 1724 grams of mass while providing 3330 cm^3 of buoyancy.

	SUM of Total Mass (g)	SUM of Displacement (ml)	Fg (N)	Fb (N)	Delta N (N)
Arm	443.9	128.6	4.4	1.3	-3.1
Electrical Housing	1415.1	2341.9	13.9	23.0	9.1
Frame	1423.1	1011.6	13.9	9.9	-4.0
Thrusters	885.0	525.0	8.7	5.1	-3.5
Grand Total	4167.1	4007.1	40.8	39.3	-1.6

Buoyancy calculations. Image: D. Baraty.

With these ideas in mind, as well as a handful other simple engineering concepts, we chose the motor layout that roughly simulates the motion of an airplane. One motor acts as an elevator on the tail of the craft. It produces a force vector non-collinear with the center of mass (under the pressure housing), which, by the laws of Newtonian mechanics and the principles of torque, generates a rotational motion. This causes the ROV to pitch up or down. The direction of this pitching motion is dependent on the direction of water flow through the motor. Two motors located on the left and right of the center of mass provide forward/backward translational motion as well as the yawing motion. These motors also produce a force vector non-collinear with the ROV's center of mass, resulting in two torques. However, when both motors are running at the identical speeds and directions, the two torques cancel, which causes in a net translational motion. For yawing motion, the motors spin at different velocities, creating a torque that results in the craft's rotation about its center of mass. A fourth motor positioned underneath and collinear (in the y-axis) with the ROV's center of mass to allow the ROV to crab side-to-side for more precise tasks, was removed after testing revealed the crabbing motion was not as effective with our frame strongly resisting sideways translation. We decided after extensive testing in the pool that the added weight and power for this fourth thruster was not worth the added weight or complexity. Our pilots decided they could more easily reposition the craft using the existing three motors. So, we simplified the operation of *True* to focus on maximizing surge, yaw, and pitching motions while minimizing rolling and swaying motions. Aligning the center of buoyancy above the center of mass, we aimed to enable our ROV to right itself when flipped or rolled, minimizing rolling and providing an inherent stability to *True*.

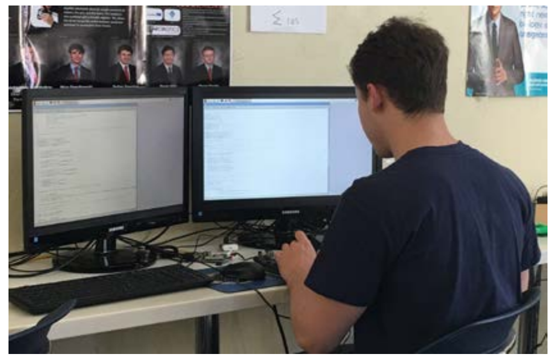
The arm on the front of the craft serves two purposes. First, it balances the weight of the pitch motor on the back of the chassis. This prevents *True* from having a high attack angle. Second, its three degrees of freedom enable the ROV to grip, manipulate, and control objects in the underwater landscape. This is an important ability, given that our ROV is designed to perform routine tasks in hostile environments. As an artificial appendage of the ROV, it can easily manipulate a buried undersea object or retrieve critical equipment. In essence, the mechanical arm serves as the craft's manipulator as well as its external moment arm which can exert torque on an object or in the water column to either rotate itself or to cause rotation.



Robotic arm main assembly. . Photo by Ceylin Sener.

We mounted a single camera inside the pressure housing on a vertically-positioned servo with 150° of motion. The driver can control this servo to change his field of view up and down using a button on the control stick. The ROV's custom written companion application allows the user to take unlimited screenshots and to display two of these screenshots at any given time. This feature helps combat the loss in field of view. We chose to use an analog camera to reliably send the video feed over our approximately twelve meter tether. Ultimately, this camera provides a cheap and effective field of view to pilots without the delay inherent in digital Raspberry Pi mounted or USB cameras we tested.

True's control and electrical systems a features two Raspberry Pis that handle the thruster, servo, arm, camera, and independent sensor control in addition to the flow of data to and from the craft. The Raspberry Pi 3, a small single-board computer capable of running versions of the Linux OS, both sends information up the tether via a packetized data protocol and receives such data from the command center on the pool deck. The Raspberry Pi also indirectly handles thruster control. We programmed the Raspberry Pis in Python and the data from the pressure and temperature sensors are sent to the Raspberry Pi over an I^2C, or Inter-Integrated Circuit, Connection. Using previously developed advanced technology, we can take advantage of the Raspberry Pi's ability to interface with thrusters via Electronic Speed Controllers (ESC's), arm and camera servos using Pulse Width Modulation (PWM) pins, and sensors via the I^2C interface without having to reinvent the wheel.



CTO Dylan Spector programs *True* in Python, allowing two Raspberry Pis to communicate and coordinate all ROV components. Photo by Ceylin Sener.

Confusing? Just remember that the piloting experience requires no knowledge of control systems. Push the joystick, and *True* will respond. Use the gamepad controller and watch the robotic arm move on the video screen, while simultaneously displaying sensor data. Click a button, and save a virtually unlimited number of photographic snapshots to the 32 GB micro-SD card. It's intuitive so mission specialists can focus on their tasks, not on their equipment. It's designed following FBC to allow advanced ROVs using established and tested technologies. It's built from tested and advanced materials in our workspace in Pottstown, PA so that we can bring a design from the virtual drawing board while maximizing capability and containing costs quickly and efficiently.

III. Safety

A. Company Safety Philosophy

As clichéd as it may sound, we believe that safety is not merely a set of strict protocols to be followed, but an ever present mindset alive in the workshop. Our employees perform every task, no matter how trivial, using the appropriate safety equipment and procedures. In addition, our employees exercise vigilance to unforeseen elements of tasks that could slip through the cracks in our protocol and cause a hazard. Take soldering PCB boards, for example. Not only do our team members at Sea Rams follow procedure by wearing wraparound safety goggles and by using solder fans to suck away toxic lead fumes, but they also are conscious of the environment around them: they are careful to keep the iron under control at all times to prevent burns and they are on guard against stray bits of hot solder that fall off the iron.

B. Vehicle Safety Features

Our safety philosophy permeates the design features of Sea Rams' new ROV *True*. The miracle of our ROV is that we managed to engineer it to be both aesthetically pleasing and efficient in function without cutting any corners. Every component of the ROV holds "true" to Sea Rams' rigorous company standard of safety (in part, hence the name).

Laser cutting plastic allows for smooth curves with no evidence of burrs or sharp edges to cut skin. Blue Robotics T100 thrusters, approved by MATE, contain housings that prevent accidental digital insertion into a spinning blade. These areas, nevertheless, bear bright orange marking to indicate danger areas. Operators should exercise caution, but our designers have gone to lengths to select components and processes that shall enhance job safety.

True's wires are contained in a sheath of non-conducting plastic. In addition, every wire-to-wire and wire-to-PCB interface is either soldered, interfaced with male/female bullet connectors or secured in wire taps. We have contained all wiring by one of the above means or covered in plastic heat shrink wrap to minimize the risk of a short circuit.

In addition, *True* has a 25A fuse installed on the main power supply line to prevent overamping the system. However, a blown fuse in operation would mean the loss of power to all systems, an issue which would cost valuable time to fix. To prevent this potential issue, *True* goes the extra mile by implementing code in its software which carefully regulates the current draw of each underwater component (motor, Raspberry Pi, etc.) to prevent the fuse from blowing.

Lastly, we certify that all components outside of the pressure housing are innately waterproof, designed to be waterproof, or have been manually waterproofed by SeaRams team members. The frame does not conduct, and the four T100 thrusters, pre-designed to be waterproof, protect from electrical shorts. Each servo, carefully and precisely waterproofed with epoxy, marine grease, and food-grade mineral oil, should work at depth with no intrusion by water into the servo. The pressure housing, designed to withstand and tested to 100m depth or 1000 kPa, will definitely survive in depths to 10 meters. We pot every wire passing through the housing to prevent leaks. Waterproofing, essential in underwater engineering because water's hostile effect on electronics, allows *True* to exceed all waterproofing requirements necessary to keep sensitive systems safe and stay operational.

C. Operational and Safety Checklist

The checklist ensures that Sea Rams team is Go!

1. Team
   a. Are all team members present?
   b. Safety glasses on.
   c. Make sure that all team members wear close-toed shoes
   d. Do you have a game plan? Do all team members have the same plan?
2. Pre-Power
   a. Are all parts of the robot secured?
   b. Area clear/safe (no electrocution hazard).
   c. Is the pressure housing cap on?
   d. Is it secured tightly?
   e. Check the physical connections (penetrators).
3. Electrical Checks
   a. Make sure no wires are hanging loose.
   b. Switches/ main power in the off position?
   c. Electronics housing sealed
   d. Confirm that every required cable is connected and functioning
   e. Is the Anderson power pole connected properly?
   f. Is there a 25 amp fuse? Is the fuse good?
4. Power-Up
   a. Call out, "Powering On!"
   b. Deck members call "Powered on."
5. Launch
   a. Make sure members are ready for the launch.
   b. Call "Launch!"
   c. "Launch ROV."
6. In Water
   a. Check if there is any leakage.
   b. Check for large bubbles.
7. ROV Retrieval
   a. Call "ROV ready for retrieval!"
   b. Stop the thrusters when ROV is captured.
   c. Power down the connections.
8. Leak Detection
   a. If seen leakage, surface immediately.
   b. Power down the robot.
   c. Try to figure out where the leakage is coming from.
   d. Confirm that there are no leaks.
   e. Turn the ROV on.
   f. Resume mission.

IV. Logistics

A. Schedule and Project Management

To keep everything running smoothly we created a schedule and timeline of when all the major tasks needed to be completed.We made sure to incorporate dependencies. Dependencies are when one task cannot be started until another task is completed and there were several parts of the project had dependencies, especially in regards to ordering materials, T-shirts, business cards, etc. An example of dependency: the team could not assemble of the robot arm until the materials were ordered, and we could not order T-shirts until we first had a graphic design.

We also divided the task of building the robot into several teams. Some of teams we had were the design team, arm team, finances, and video. Even though several people were on more than one team, it added to the efficiency of the robot building by allowing us to complete many tasks simultaneously.

One major factor that contributed to successful project management was communication. Every day, at the start of class everyone would give updates on what they were working on. Communication is what helped us figure out what teams had too much work, what teams had too little, and ultimately disperse the work force. We used several other tools to communicate with each other. We used to GitHub™, Slack, and google docs to update each other and show each other our progress outside of the classroom.

Because of our effective communication we were able to make and agree on deadlines for when parts of the robot needed to get completed and to get started. For example, we were able to discuss how long the design, arm, and code should take in order for things to be done in a timely fashion. One of the good things about our project management was the ability to be strict with our deadlines. If one of the teams were struggling with the deadline other members from other teams joined to make sure it got done on time instead of extending the deadline.

B. Source Code Management

In order to keep track of our code and to allow multiple people to edit it, we used GitHub™, an online service that hosts code for programmers. It uses git, a system used for both software development and version control. Through GitHub™, our programmers can edit the code from any computer, and at the same time. GitHub™ also provides features for organizations to post and track known issues, and questions about the code.

C. Budget and Project Costing

Category	Part	Number	Price	Net Price
Electro	Raspberry Pi Model 3	2	$39.50	$79.00
	Servo/PWM Pi Hat	1	$24.95	$24.95
	HS-5646WP Servo	3	$54.99	$164.97
	Tower Pro SG92R Micro Servo	1	$2.60	$2.60
	Electronic Speed Controllers (ESC)	3	$16.02	$48.06
Electro	Pololu 5V Step-Down Voltage Regulato	1	$14.95	$14.95
	5V to 3.3V Logic Level Converter	1	$2.95	$2.95
	Analog Camera	1	$33.90	$33.90
Hardware	PVC Angle Stock 2"x2"	24	$0.00: Donated	$0.00: Donated
	Water tight 4" Pressure Housing	1	54.00	$54.00
	Dome End Cap	1	$59.00	$59.00
	Aluminum end cap 10 hole	1	$24.00	$24.00
	Cable Penetrators	10	$4.00	$40.00
	Delrin	4	$15.88	$63.22
	O-Ring Flange	2	$29.00	$58.00
	T100 Motors	3	$144.00	$432.00
	Waterproof Temperature Sensor	1	$56.00	$56.00
	Waterproof Pressure Sensor	1	$68.00	$68.00
	Video Ray Tether Cable	1	$0.00: Donat	$0.00: Donate
	Aluminum Beam (for arm)	1	$0.00: Donat	$0.00: Donate
	Grasper	1	$0.00: Donat	$0.00: Donate
Total Cost:				$1225.60

V. Conclusion

A. Challenges

1. Technical Challenges

As we were designing the chassis on SolidWorks™, we faced some difficulties. We had to determine the design of the chassis so that it would allow the robot to move freely in the water while having enough space for the pressure housing. It also needed to be small enough and light enough to receive bonus credit in the competition. Partially due to the need to include the tether in size and weight, we also designed the ROV in the shape of a capital H, so that the tether can easily be wrapped around without much risk of tangling or breaking. It is also worth noting that, this is the first year that most of our team has worked in SolidWorks. This resulted in the challenge of learning how to most efficiently use the software. Thankfully, our technical adviser, Mr. Timothy Jump, incorporates SolidWorks in our new engineering training program, and was able to give us guidance on the use of the software.

2. Non-Technical Challenges

All members of SeaRams are students at The Hill School, a boarding school where all students have challenging schedules from morning to night. This made finding time when all members of the team were available to work on the ROV difficult. This often led to only a few members of the team in the lab at a time. In order to communicate effectively with one another, despite being separated, we used the messaging app Slack™ to easily share files and to integrate with GitHub™. Our team used GitHub™ to keep track and work on the software behind True ROV together. By integrating GitHub™ with Slack™, we were able to receive messages from a GitHub™ Bot about new Commits, Issues, or comments on the code.

B. Lessons Learned and Skills Gained

Creating a submersible robot that can do several difficult tasks can be quite daunting, however with the help of other passionate students and classmates this task became possible. The biggest and most prominent interpersonal lesson learned was working with people we aren't familiar with and being able to cooperate and compromise with the thoughts and ideas of each other. We learned how to stand in front of our classmates and be comfortable explaining our opinions and points of view.

Beyond the interpersonal skills, all members of the team learned new technical skills as well. The Freshmen on our team were all completely new to both Robotics and Programming. Due to knowledge base, they spent much of their time assisting the older members of the team. We encouraged them to ask questions about what they are seeing or doing. We believe and practice the ideology that you learn more from doing, than by studying. The youngest members of Sea Rams provide the prime example of this. By the competition, these members had learned how to program and work two Raspberry Pi 3, solder, and program in Python. The list does not end there for our freshman, and our older members have learned their own skills as well.

C. Discussion of Future Improvements

When we think ahead to future endeavors one major improvement comes to mind, Virtual Reality. Virtual Reality is becoming a consumer item for the first time and our device could be fitted to support Virtual Reality given some time and experimentation. This would allow our pilot to interact with the underwater world in a way impossible through a standard setup. It would be like having a diver on scene assisting with the mission, and being able to sense the world around the pilot would allow them to react quickly to their surroundings. Virtual Reality has been marketed deeply to the gaming crowd, but we recognize that Virtual Reality does not have such limitations.

We are scheduled to have new high quality 3D printing equipment available for our use next year. The ability to print small and intricate parts for our ROV as a whole would drive production costs down and decrease time wasted waiting for orders to be delivered to our lab.

Another topic of improvement is that of the arm. Our ROV's arm currently extends out into the water at all times. Instead, our arm could retract underneath our ROV to decrease size and to decrease drag in the water. Having the arm retract into the craft would also make the arm less of a liability and reduce the risk of clipping an object and damaging the arm. In order to implement this concept, we would only need a servo, and track for the arm to rest and slide on, attached to our ROV. Examining ways to operate the arm through a pressure housing using seals would also allow us to protect and preserve our servos to make them resilient to water.

D. Reflections

For most of us, MATE has been the culmination of three years of work together. Starting as Sophomores and Freshmen in introduction to Computer Science through Computer Science AP and now into Advanced Seminar, we have grown together. This ROV has allowed us to take the skills we learned in the classroom and use them in a real-world scenario. It never mattered how impossible the task seemed or how daunting the project we pulled together and got the job done. As a group we fit together like a puzzle; everyone brought their own skills and experiences to the table and everyone was utilized. Those who were particularly skilled in one area made sure to share their knowledge and help others learn.

One of our biggest challenges was fatigue and pressure from other classes. Legendary football coach Vince Lombardi once said, "Fatigue makes cowards of us all." The meaning isn't as straightforward as it seems. Fatigue is more than tiredness, it is the complete exhaustion of the mind and body, and everyone reaches this point especially when dealing with sports and five other classes that are demanding. During this marathon we reached points where we stalled out and things that should have been done weeks prior were still unchecked, but that is all part of the process. We learned from this and learned that work put in early will pay off exponentially. Unfortunately things do not always follow the plan, but the ability to adapt quickly and get the work done is an essential skill in today's world.

Our class has become much closer because of MATE and we are all invested in our product and this competition. It has almost never been easy, but we fought through and got the job done. We learned to trust our peers to get their jobs done and our leadership to steer the ship in the right direction. Our technical knowledge has grown immensely, but our ability to work together and work as part of a large team trumps that.

This has been an incredible experience and one that will not soon be forgotten.

E. Sponsors/Acknowledgements

- MATE-PA: for hosting workshops and providing the influx of information, inspiration, and materials to start our season these past two years.
- The Hill School: for financial backing and support in every way possible. Specifically:
  - Gary Arthurs; Wood Shop Artist in Residence, The Hill School: for technical support and the use of tools and equipment.
  - TJ Marchesanti; Graphic Designer, The Hill School: for work finalizing our team logo.
  - Tim Jump; Engineering^3 Program Director, The Hill School: for providing a solid background in all types of engineering and design thinking and allowing us to advance to the next level of ROV development.
- VideoRay: Marcus Kolb et al., for leading a tour and inspiring the troops on a visit to the VideoRay Research Barn.
- gPARSEC: for use of their equipment, inspiration, moral support, and expertise from the Owen J. Roberts Sea Dog Underwater Robotics Team.
- Plastic Supply of Pennsylvania, Inc: for donating the angle PVC plastic to mount our motors and supplying our Delrin plastic for our frame.
- SolidWorks: For donating 3D software for installation on student PC's.
- MATE: For overall support and amazing summer institutes pushing the boundaries of marine technology education, online building references, and textbook from intermediate level workshop.

References

Blue Robotics. *Blue Robotics: Marine Components, Parts, and Supplies.* <https://www.bluerobotics.com/>. 2016.

Fraser, Scott. MATE ROV Diving Into Sensors. <http://www.kn6f.com/ROVsw/course/view.php?id=2>. 2015-16.

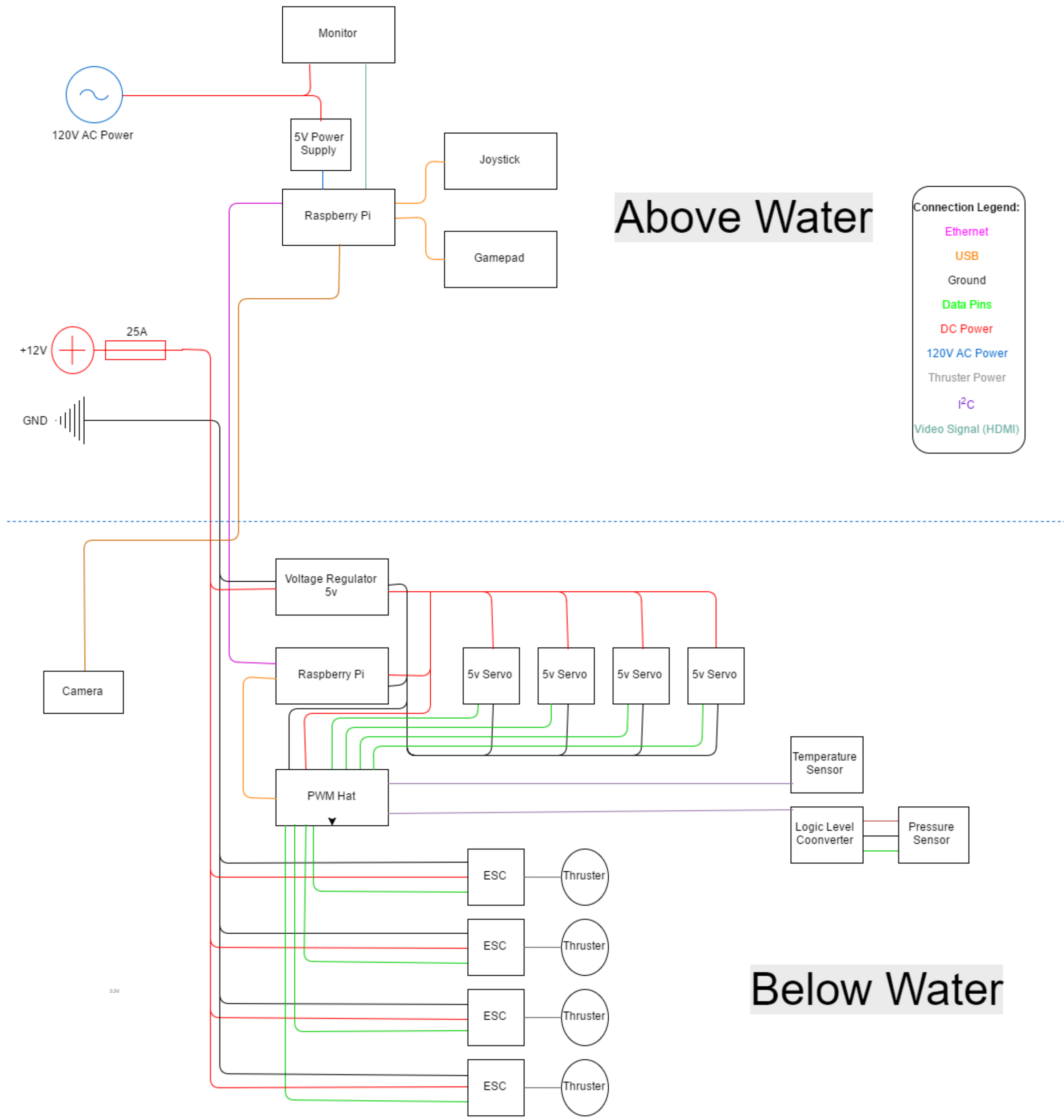
Marine Advanced Technology Education Center. *Beginner ROV Workshop*. 2006??. Monterey Peninsula College.

Marine Advanced Technology Education Center. *Intermediate ROV Teacher Workshop*. 2015. Monterey Peninsula College.

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

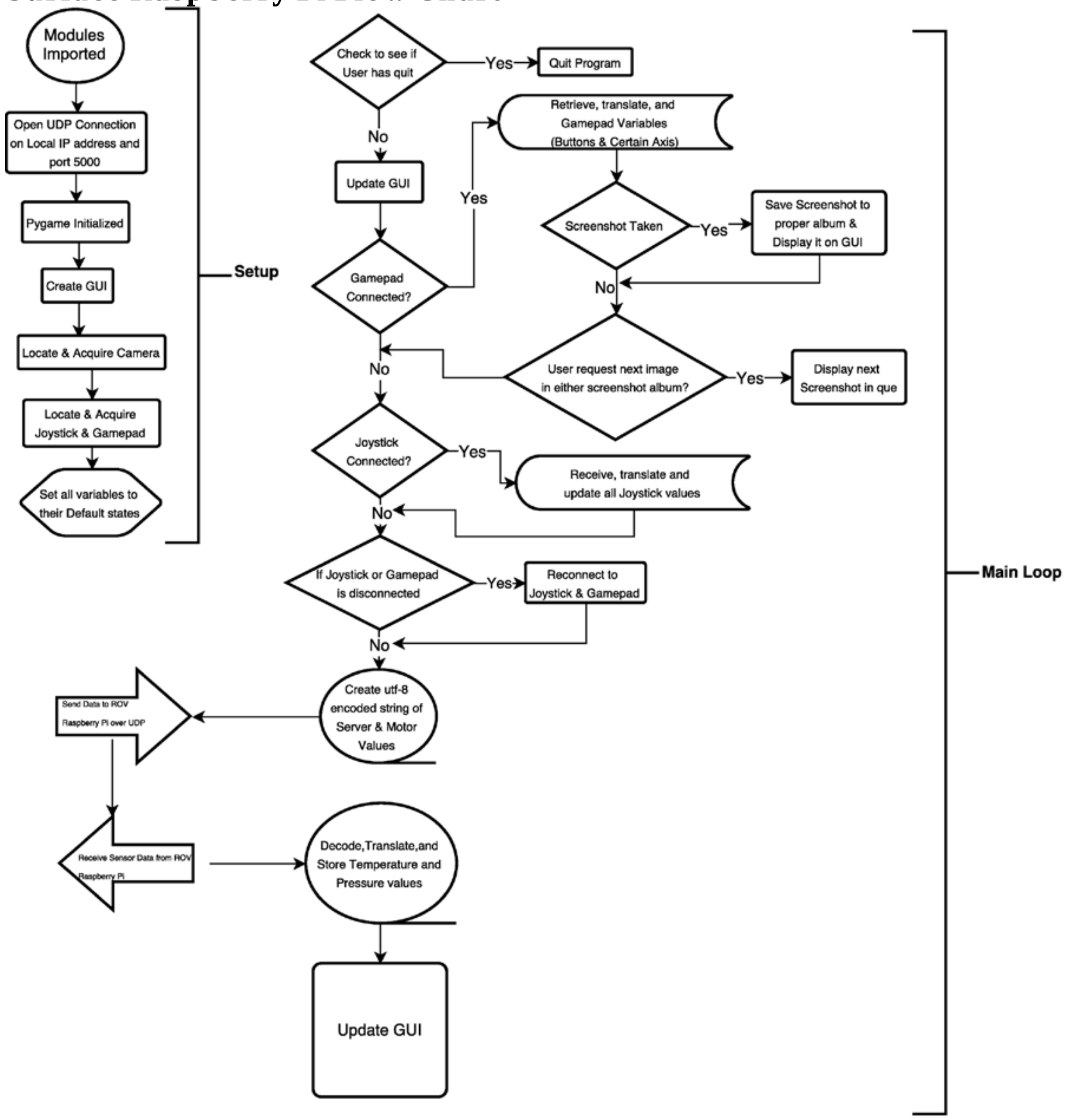
NASA. *NASA FBC Task Final Report*. <http://mars.nasa.gov/msp98/misc/fbctask.pdf>. 2016.

Appendix A. SID (System Interconnection Diagram)



B. Flow Charts

1. Surface Raspberry Pi Flow Chart



2. ROV Raspberry Pi Flow Chart