Figure 1 - ROV Full Assembly

ROSE-HULMAN ROBOTICS TEAM

Rose-Hulman Institute of Technology

Terre Haute, IN

COMPANY MEMBER	ROLE
Christian Balcom	Team Leader CSSE / EE
Riley Shore	EE
Connor Crenshaw	EE
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Megan Korbel	ME
Kyle Brown	ME

Faculty Advisors

Dr. Ryder Winck

Dr. Simon Jones

Abstract

The Rose-Hulman Robotics Team (RHRT) is a student-led company from Rose-Hulman Institute of Technology in Terre Haute, Indiana. After a one-year hiatus from the Marine Advanced Technology Education (MATE) robotics program, RHRT is ready to return to competition in the Explorer Class International Competition.

RHRT's ROV includes many ideas from previous years, but it is a new vehicle that has been newly designed for this competition. There are several concepts and parts that have been re-used from last year, but the company was unable to complete the ROV that year. This ROV includes several features from that incomplete design, but anything taken from the previous model has been completely revamped to suit our new design. Not including the tether, this ROV weighs in at 15.55kg and the largest diameter (excluding the gripper arm) is approximately 52cm. This should put the ROV in the smallest size bracket, but the addition of the tether brings the weight up to 19kg, putting it in the medium weight bracket. The ROV has a single camera mounted below the primary frame and angled to give the pilot a view that is both useful for precision maneuvering when utilizing the gripper and wide enough to view the environment and get his/her bearings.

Design and fabrication of this ROV began in August of 2017 and continued until late April. Testing and refining of components occurred throughout the entire process, culminating in the ROV shown below by mid-May. The project budget was approximately $15,265, provided mainly by Rockwell Collins and Rose-Hulman Institute of Technology.

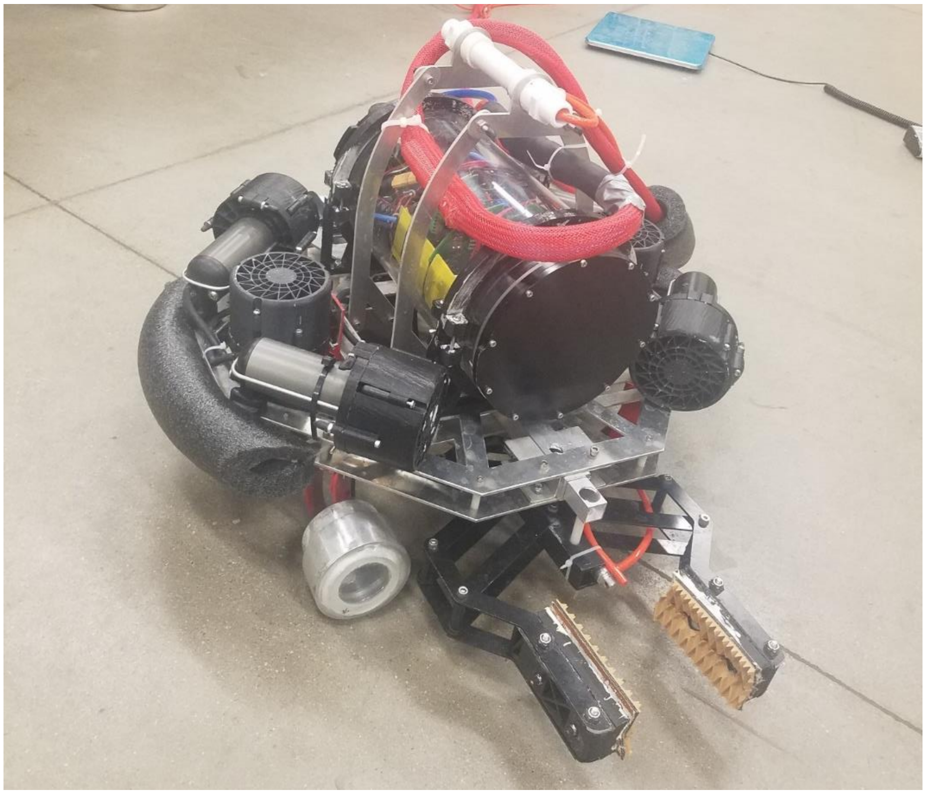

Figure 2 - Completed ROV (as of 5/21/2018)

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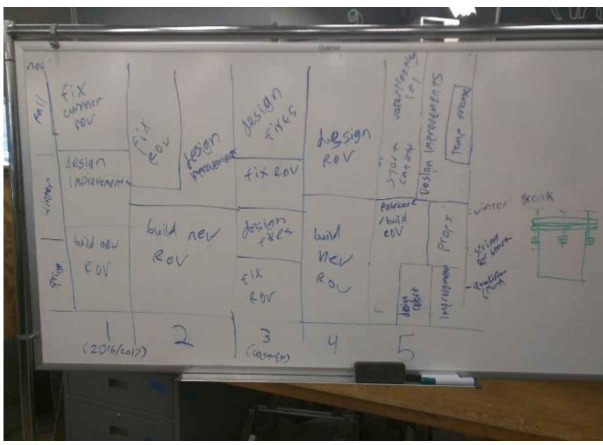
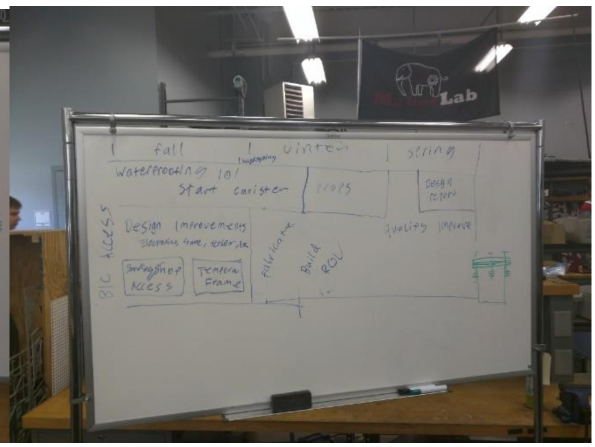
Teamwork

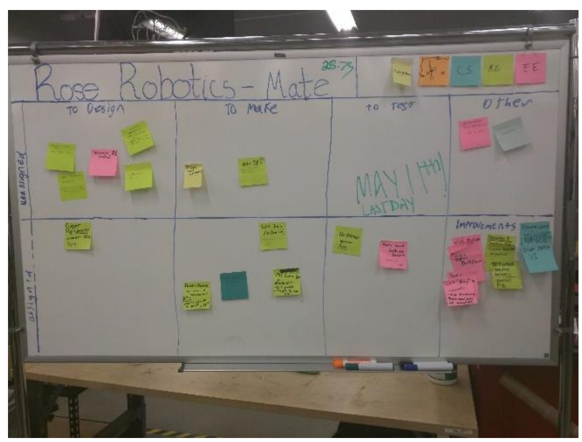
Project Management

At the start of the year, the team spent several evening meetings discussing potential timelines for the project. With a new group of students, it was important to define the objectives of the team over the year. For example: did we want to prioritize robot quality? What about new student growth? How important was competition? Answering these questions lead the team to the timeline we started the project with.





As the year progressed, it became necessary to maintain an informal report of the team's progress and work assignments for different components and disciplines. This was implemented in the form of a Kanban board, and allowed the entire team to monitor the progress of individual sub-projects and to assist as necessary. This also functioned as a source for students to select new projects when they finished previous responsibilities



Teamwork

The tasks of building any robot can often be divided into three main disciplines: Mechanical Engineering, Electrical Engineering, and Computer Science. While the majors of individual students usually dictated the majority of the work that student would do, we strove to promote interdisciplinary education whenever possible. For example: every student on the team, ME or not, had some part in the design, machining, and mechanical assembly of the robot. Several of the MEs learned to solder for the project, and many questions were asked and answered between the skillsets present on the team.

Mechanical Design

Mechanical Overview

This section details the mechanical department's processes and design work for the ROV. The work on design, manufacturing, and testing of all components of the vehicle were distributed among the small group of MEs on the team. We did this in such a manner that all MEs were able to contribute to the team's progress in a meaningful way while also learning new concepts and processes.

All watertight parts were tested extensively before ever housing delicate electronics or being used on the ROV. They were tested first at a depth of 2 feet for 20 minutes in a metal trough before being tested at the bottom of a pool (12.5 feet) for 20 minutes.

Frame

The main body of the ROV is made from 1/8 inch aluminum sheet. We designed the frame in SolidWorks and confirmed in an assembly that all of our parts would fit together as intended before manufacturing them. The majority of parts were designed to be made out of a flat sheet of aluminum that we could cut to shape in a waterjet cutter on campus. As shown in *Figure 2* below, the main body of the ROV is made from two identical plates offset from each other by 1" Nylon standoffs. This is the main platform on which the rest of the ROV is built on. On the bottom we have four legs to raise the ROV off the ground and provide a buffer area to keep important components safe in case of impact from the bottom. In the center of the frame is the tether mount and handle. We included this near the end of design because we needed some form of strain relief for the tether and realized that an easier method of transporting the ROV would be very beneficial.

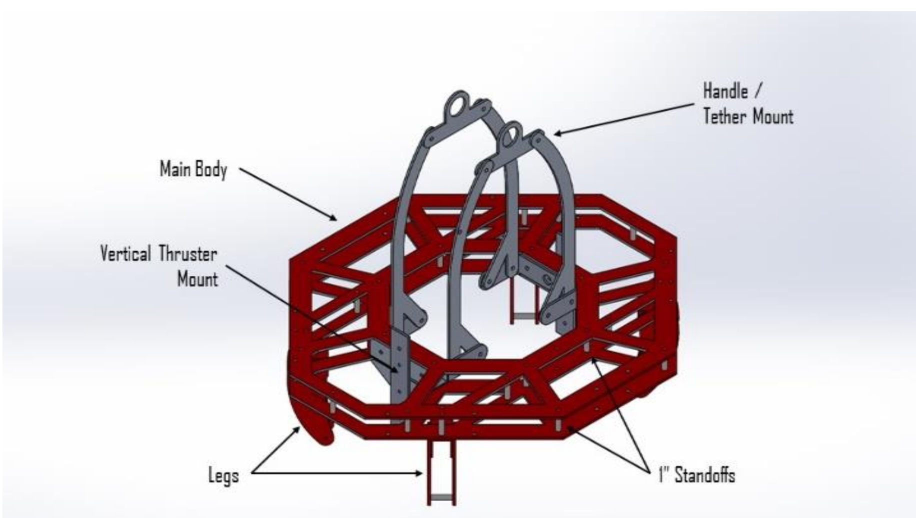


Figure 3 - Frame

The tether mount shown above is missing one piece that ended up in the final design. We used a piece of PVC pipe cut to a length about 1 inch larger than the distance between the two rings at the top of the mount. We secured it in place with a pair of endcaps. The tether is run around the top of the mount and held in place with zip-ties. We used a length of extra pneumatics tubing that was attached to the tether and tied so it will always be tighter than the tether as it leaves the ROV. This reduces the forces and strains on the bulkhead penetrators, making a leak or other failure due to a penetrator much less likely. Additionally, the length of pipe bridging the tops of either side of the mount acts as a handle, allowing a user to easily carry the ROV with one hand, rather than awkwardly grabbing two sides of the frame.

Primary Canister

The Primary Canister houses all of the ROV's electronics and prevents water from damaging critical components. We designed and manufactured our own canister with limited success. It worked well under early testing (at depths less than 3 feet) but quickly failed when tested at a depth greater than 10 feet. The seal between the lid and the canister was not strong enough to deal with the higher pressures at competition depth. We attempted to solve this several ways. Perhaps the most ridiculous idea was to line the inside of the canister next to the seal with tampons. This helped to an extent, but it was ultimately like putting a Band-Aid on a deep cut. It absorbed the flow for a little while, but it eventually soaked through. Eventually, we determined the cause of failure to be a less-than-ideal design that could have potentially worked if it had been machined more precisely. The seal between the canister and the lid was not flat or consistent enough to hold back water at high pressures. With time running down and the pressure to get a functional ROV mounting, we finally decided to purchase a Blue Robotics 6in waterproof canister. This canister quickly proved to be more than adequate and did not leak at all during testing. With the problems of a leaky canister solved, the mechanical team was free to focus on other pressing matters.

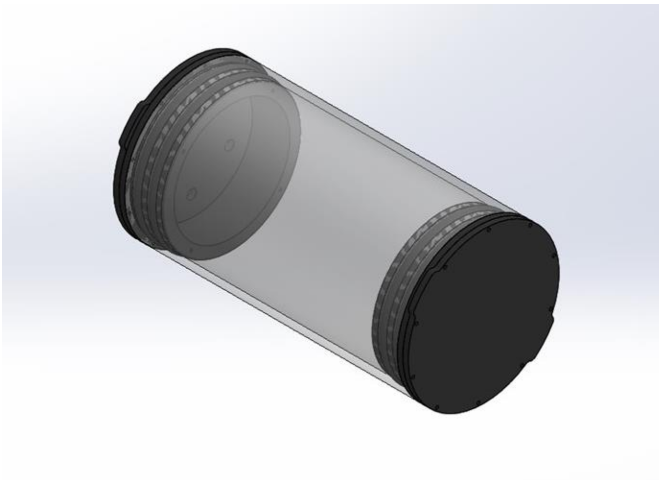


Figure 4 - Primary Canister

The next step was to make it possible for the wires from our thrusters, camera, and tether to reach the electronics in the canister. We solved this problem with the addition of bulkhead penetrators. Many different iterations of these were tested, including smaller bolts with wires and epoxy threaded through a center hole and commercially available connections. After many versions of different solutions were tested, we found ¾ inch bolts with a 5/8 inch diameter hole drilled through the center to be the best solution. A ¾ inch plate was affixed to the threaded end of the bolt, and a smaller, 5/8 inch diameter plate was inserted into the bolt. The smaller plate allowed marine-grade epoxy to fill the cavity between the two plates, preventing water from entering the electronics canister.

Solenoid Canister

The Solenoid Canister houses the solenoids that control the pneumatics system. We designed and built this canister ourselves last year. Since this canister did not need to be nearly as large as the primary canister mentioned above, we did not have any serious problems when testing its waterproofing. We decided to re-use this part from last year since it had proven to be waterproof and had adequate space for our solenoids.

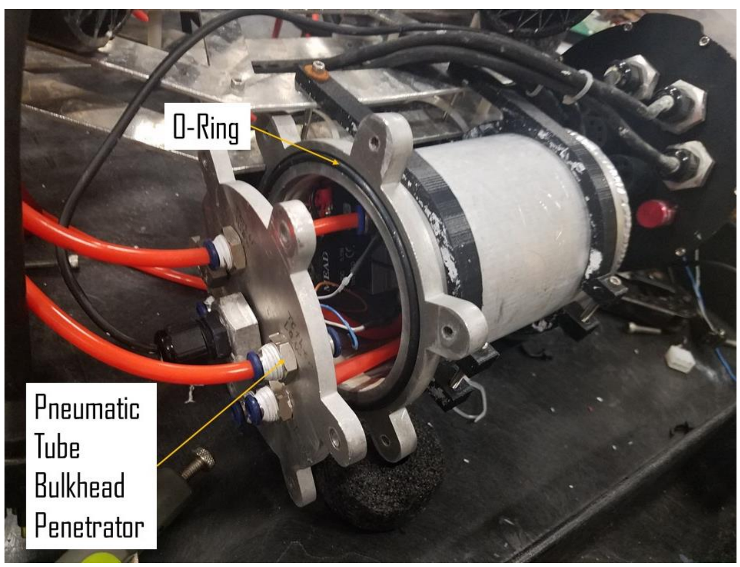


Figure 5 - Solenoid Canister

The canister is comprised of two main parts: the canister base (the piece that houses the solenoids) and the lid. The two parts are held together and made watertight using screws set radially around the canister to press the lid tight against the lip of the canister and seal an O-ring into an etched recess. This design seems to hold watertight for a while, but if the ROV is in use for an extended period of time, water does begin to accumulate in the canister. Fortunately, the solenoids are designed in such a way that even being submerged in a little bit of water does not damage them.

The lid features a series of bulkhead penetrators that allow the solenoid to connect to the electronics in the primary canister and the pneumatics tubing. The single bulkhead penetrator housing the wires is the same as the penetrators on the primary canister. The four bulkhead penetrators housing the pneumatics had to be designed differently. We used a standard pneumatics line joint for which we drilled and tapped a hole for. We secured the threads with pipe thread tape before adding hex-nuts with appropriately-sized O-rings to either side to create a watertight seal.

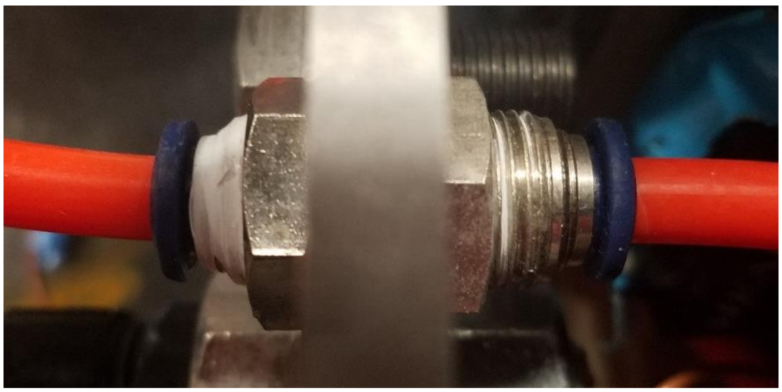


Figure 6 - Pneumatic Tube Bulkhead Penetrators

Camera Canister

For many years, the team has housed their camera in an acrylic dome pressed onto an aluminum base, and this method has worked well. The housing, unfortunately, was beginning to reach the end of its usable life, so a redesign of the system was pursued. The redesign of the camera canister was also used to small-scale prototype various designs for the main electronics canister. The final design selected underwent multiple revisions before being finalized, and is shown below.

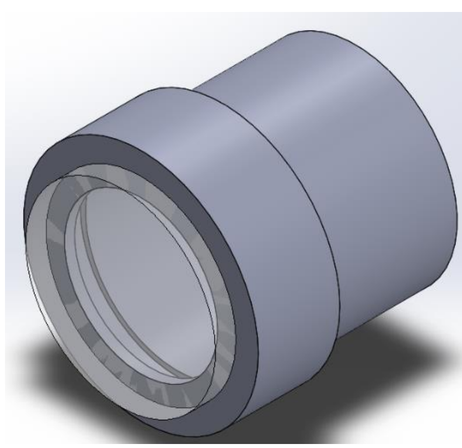


Figure 7 - Camera Canister

A 2-inch diameter aluminum cylinder was hollowed out to a wall thickness of approximately ¼-inch thick, and to a depth of 2 inches. An aluminum cap was designed to fit over this base where the interior hollow dimension is 2 1/16-inches in diameter, and the outer diameter is 2 3/8-inches. The cap is approximately 1 ½-inches in length and has a 1 ¾-inch hole cut into the top to allow a camera placed inside to see out. The base has two O-ring grooves cut into it to hold the cap on, and an acrylic lens was affixed over the outside of the cap using marine-grade epoxy. A megapixel USB camera was fixed inside the canister, and the wires pass through the same bulkhead penetrators as the primary canister.

Propulsion

For the ROV's propulsion system, we decided to reuse the SeaBotix BTD150 Standard Thrusters that we had purchased several years prior. These thrusters are fairly expensive and still work great, so we decided against trying to design our own propulsion system or buying a new set of thrusters for this year. With a continual bollard thrust of 4.85 ft/lbs, the six individual thrusters powering our ROV are more than strong enough to move the vehicle while it carrying any of the props attached to the lift bag.

Manipulator Arm / Gripper

The manipulator arm is a modified version of a manipulator arm that was designed for a robot last year that never made it to competition. Two sets of scissoring arms (cut from 1/8 inch aluminum sheet) are laid on top of each other, separated by 1-inch Nylon standoffs and the aluminum centerpiece that houses the pneumatic piston. The piston is powered via pneumatic tubing that runs from the solenoid canister at the rear of the ROV.

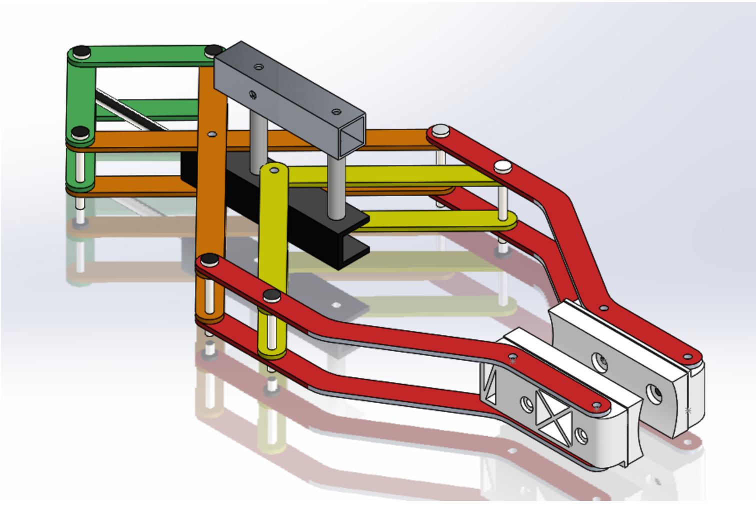


Figure 8 - Manipulator Arm and Gripper

(In the figure shown above, the arms were colored to improve the ability to distinguish each piece of the scissor arms from the others while performing motion studies and statics analyses in SolidWorks)

The gripper "hands" at the end of the red arms are made of 3D-printed ABS. These hands are split into two distinct pieces: a universal base that attaches directly to the manipulator arm and an attached gripper piece. We went with this two-piece design rather than a single solid part to speed up testing. With this design, we could quickly swap different gripper pieces out to test their effectiveness simply by unscrewing and screwing two nuts. Shown below are examples of two of our concepts for the gripper.

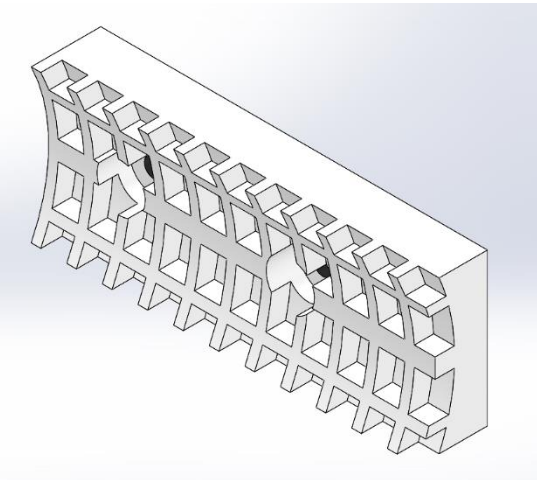


Figure 9 - Ridged Gripper

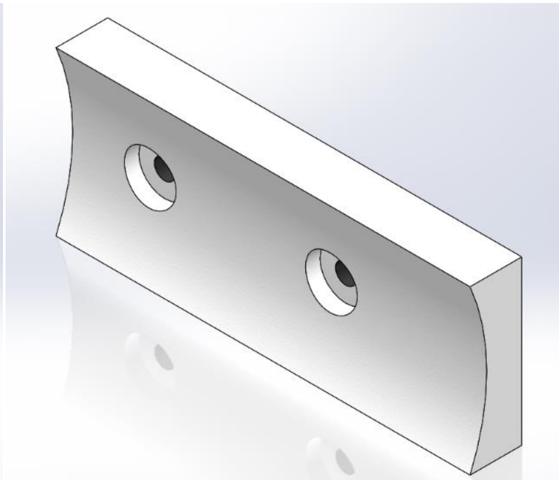


Figure 10 - Smooth Gripper

Our final design for the gripper arm (shown below) is based off of the smooth gripper. We epoxied two sets of cut, textured, rubber track to the surface of the gripper to improve its grip. The curved shape of the gripper also appeared to have a slight advantage over similar, flat-faced counterparts.

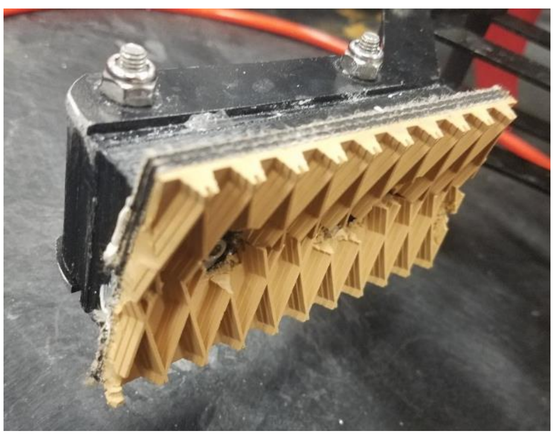


Figure 11 - Final Gripper

Lift Bucket

The lift bag we developed is not so much of a bag as a bucket. Instead of a soft, flexible bag, we have an inverted bucket attached to a PVC stem and hook. We decided to use this design because the rigidity of the bucket and the stem means the ROV can manipulate it fairly easily, without anything flopping around in front of the camera. The vehicle can even empty the bucket of air while still underwater, as long as the bucket has not been filled overmuch.

The stem of the lift bucket is split into two pieces: the main stem and the hook. The main stem is permanently fixed to the bucket and is where the ROV grasps and moves the bucket. The hook portion is not fixed in place; rather, it is held in with a locking pin to prevent the hook from moving until the ROV manually disengages the pin. This makes it rather easy for the ROV to remove the lift bucket from an object when it is done maneuvering it.

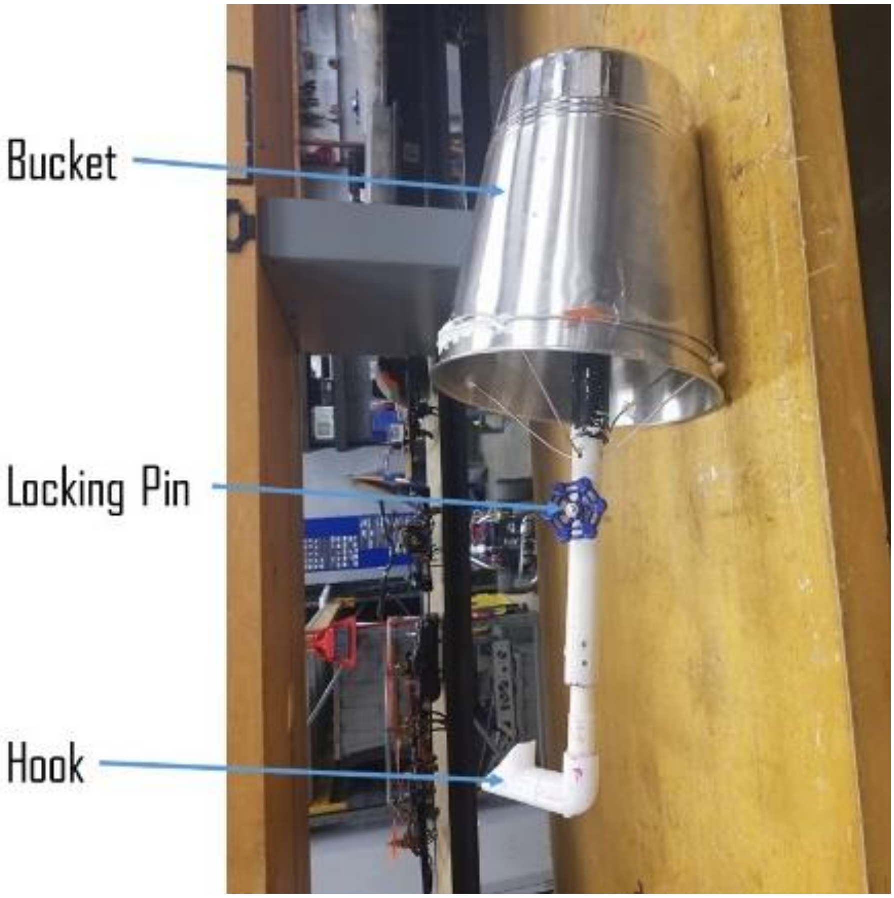


Figure 12 - Lift Bucket

The bucket does not have its own method of increasing buoyancy. Instead, the gripper arm of the ROV has a “bubbler,” which is just a pneumatic tube that is left open on one end. Once the ROV has hooked the lift bucket to the object it wants to lift, the bubbler releases a stream of air that fills the bucket.

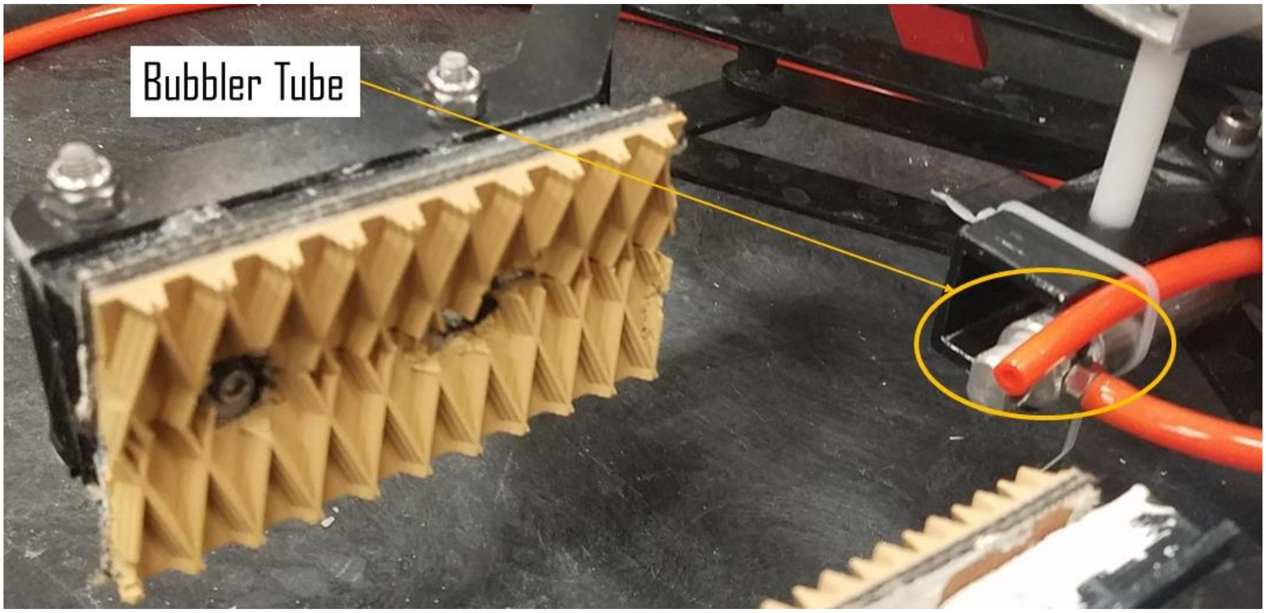
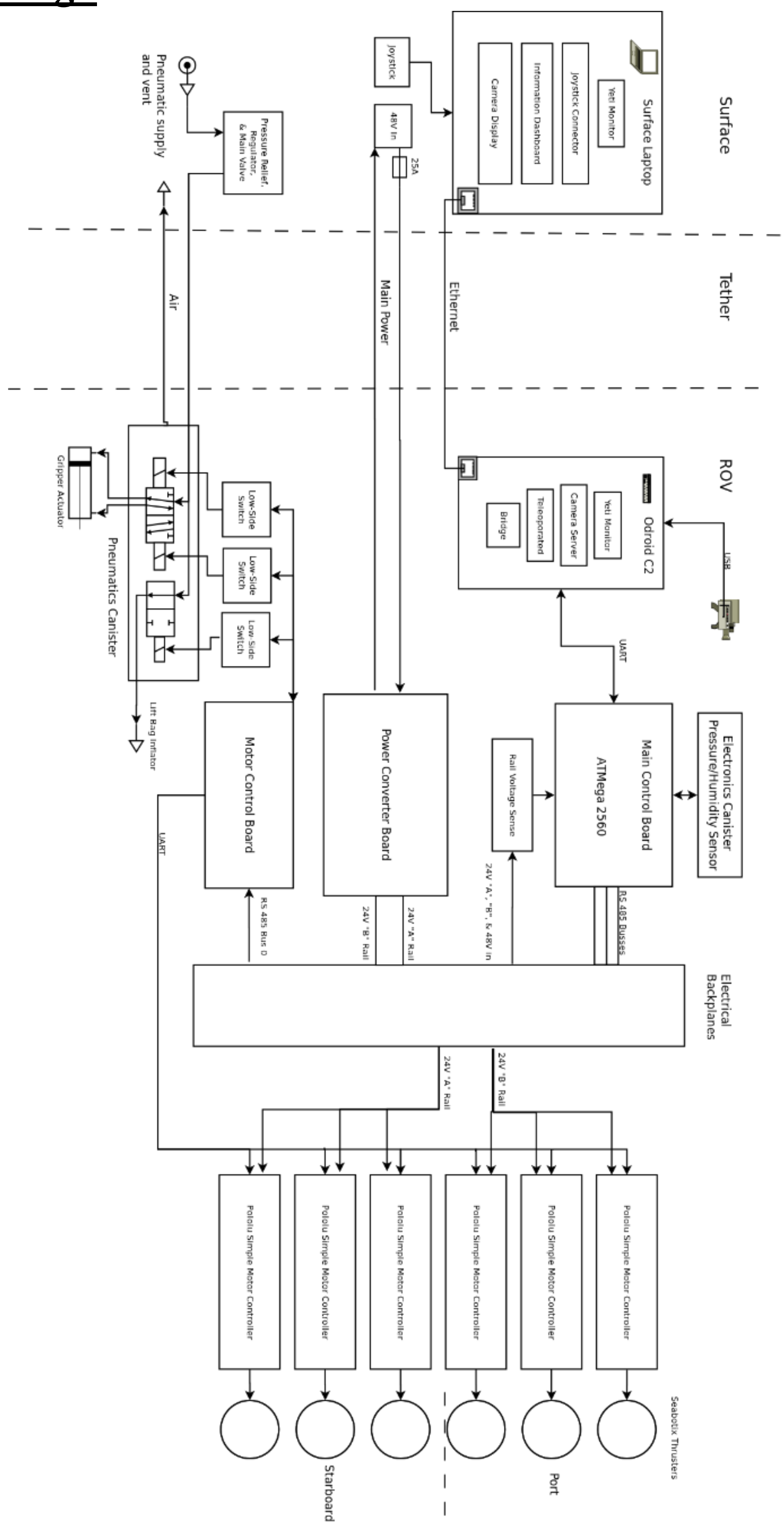
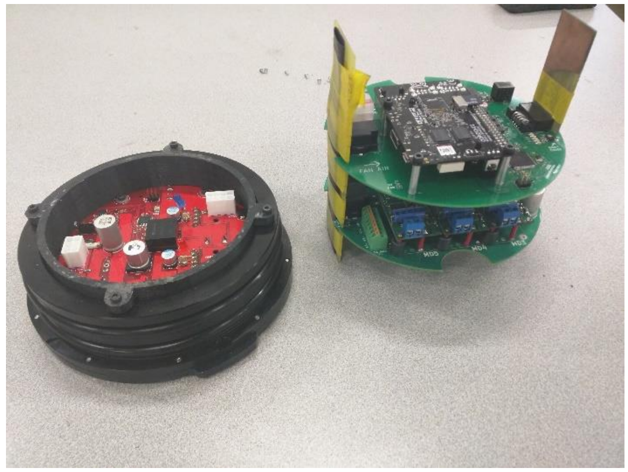


Figure 13 - Bubbler Tube

Electrical Design





The electrical system is designed to maximize the performance and reliability of the ROV. 48V is provided to the vehicle over the tether, and a custom power conversion board regulates this for two 24V rails. Each rail powers three of the six thrusters in the ROV – which are controlled with Pololu Simple Motor Controllers. The electronics stack is managed by a chain of ATMega microcontrollers and an Odroid C2 SBC running Arch Linux. Physically, the control system is split into discreet circuit boards to further promote maintainability and ease of troubleshooting.

Software Design

The software design is based on the Yeti Robotics framework – a system written by a CS student originally for use in the FIRST Robotics Competition and now adapted for the MATE competition. The Yeti framework is designed to isolate logical components of the robot and to regulate communications between them. This allows backup modules to be maintained as substitutions for the primary software modules in the case of a bug introduced into to the main version.   Another advantage this framework gave our ROV was the dynamic communications layer – allowing modules to seamlessly resume operations in the event of a temporary network failure.

The software for the ROV is divided into six Yeti modules (Input, Dashboard, Camera-Surface, Teleop, Camera-ROV, and Bridge) and three ATMega firmware projects (main control, motor control, power supply). The Yeti modules run on either the surface laptop or the Odroid C2 onboard the ROV. A chain of microcontrollers is then responsible for distributing drive commands and reporting back sensor data.

Technical Challenges

Electrical

One of the most difficult issues the electrical team had to troubleshoot was centered around undesired noise on the motor driver control traces. As we would eventually figure out, the switching action of the Pololu motor controllers is not well isolated from their power input traces. Under heavy load, the pulses would radiate from the power input leads and induce voltage spikes in the motor controller's serial input pin. This issue ultimately excluded us from the competition in 2017. After several months of diagnosing the issue, a board revision was made that added several filtering elements to both the power and serial lines. This completely solved the issue.

Mechanical

As every team has experienced, custom- machined canisters are hard to make. We began the year with designing a custom-built canister on top of several previous years of experience. The development of this was rocky from the start, as several competing designs were driven forward in parallel – and none succeeded. One design was eliminated after the initial draft, while another encountered difficulty with machinability – and ultimately had to be postponed in order to build a robot on time.

Another problem that we experienced came up when designing new prop guards for our thrusters. While designing a prop guard to meet the new safety requirements was not a particularly challenging task, it took quite a few iterations before we had a design that cleanly fit with the thrusters already in use, due to some difficult geometry involved with the mounting points on the thrusters. In fact, at one point we believed we had solved the issue and had a prop guard that fit onto the thruster, albeit a bit snugly. Unfortunately, this guard was a bit too snug, and the mounting point snapped when we tried to remove the prop guard in favor of a new design. We eventually solved the problem when we found an official 3D model from the company of the thrusters we were using. Having the model made it much easier to adapt the design for the thruster, rather than trying to guess based on rough measurements.

Future Improvements

Mechanical

- A full-frame powder-coat would greatly improve the durability and professional image of the vehicle.
- While the new prop guard design introduced for the thrusters meets safety requirements, we would like to redesign them to have a smaller impact on overall thruster strength.
- The pneumatic gripper does the job well enough for now, but we believe it could still be improved. Perhaps adjustable strength of the grip or a sturdier frame.
- The current pneumatic setup causes the bubbler to release small amounts of air when closing the gripper. This is not a huge problem, but it can cause the pilot to accidentally “inflate” the lift bucket when adjusting the grip.

Electrical

- The ATMegas will be replaed with STM32 microcontrollers in a future revision for improved performance and easier software development.
- A number of minor changes to the power conversion circuilt board would be incorporated into future revisions, such as the addition of an I^2C isolator and additional status indicators,

Software

- A new iteration of the Yeti framework was designed, but not implemented this year. An improvement would be to complete this iteration, which would allow for much more seamless communication between the microcontrollers and the high-level Yeti modules.
- A computer-vision solution could be developed to accomplish the aircraft identification task.
- Additional status reporting functionality in the microcontroller firmware throughout the ROV would allow for much easier troubleshooting and more thorough system testing.

Safety

Standards in Shop

Safety is of utmost importance in our workspace. All team members are required to wear long pants, close-toed shoes, and safety goggles when in the workspace. If any team member needs to use the machine shop for any reason, he or she is required to be accompanied by a second team member. This reduces the risks of potential injury while working with the powerful tools such as the lathe and mill and means someone is always nearby in case an accident does occur.

Fortunately, we can honestly claim that we have had no major injuries due to or related to working on our ROV.

ROV Safety Features

The ROV includes many components that have been designed or optimized for safety.

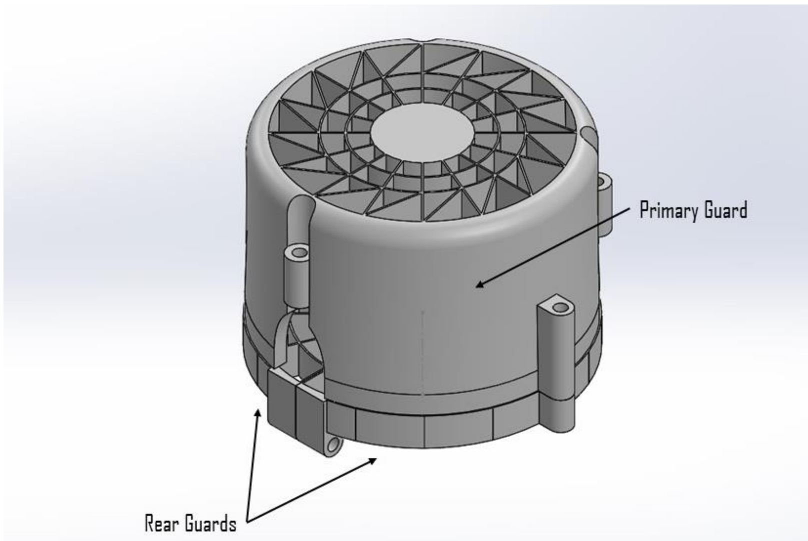


Figure 14 - Prop Guard

The prop guards that came stock with the purchased thrusters do not meet the IP-20 standards. The front of the guard has ample space for an object greater than 12.5mm in diameter to access, meaning that a human can easily fit their finger through and touch a prop while spinning. The rear of the guard has no protection at all and leaves the prop completely open. While this makes for more efficient water flow, it fails to meet safety requirements. We designed a new prop guard to fit the thrusters without any modification to the thruster itself. The new guard has been designed with smaller spaces and a rear piece that also complies with IP-20 standards.

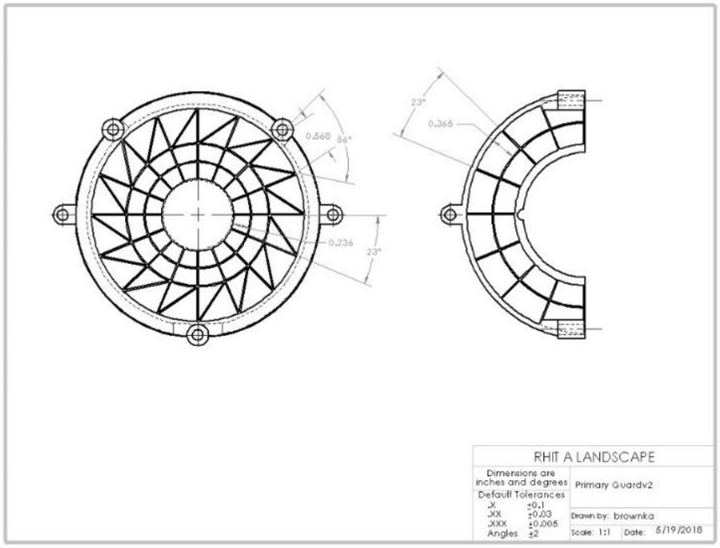


Figure 15 - Prop Guard Drawing (inches)

Another feature that improves the overall safety of the ROV is the floating pool noodles that we initially included to enhance buoyancy. We placed these noodles on the sides of the ROV in a manner that allows them to act as bumpers. They can absorb impact from the sides of the vehicle, where the camera cannot see. This decreases the chances of damage from the pilot accidentally hitting something he could not see

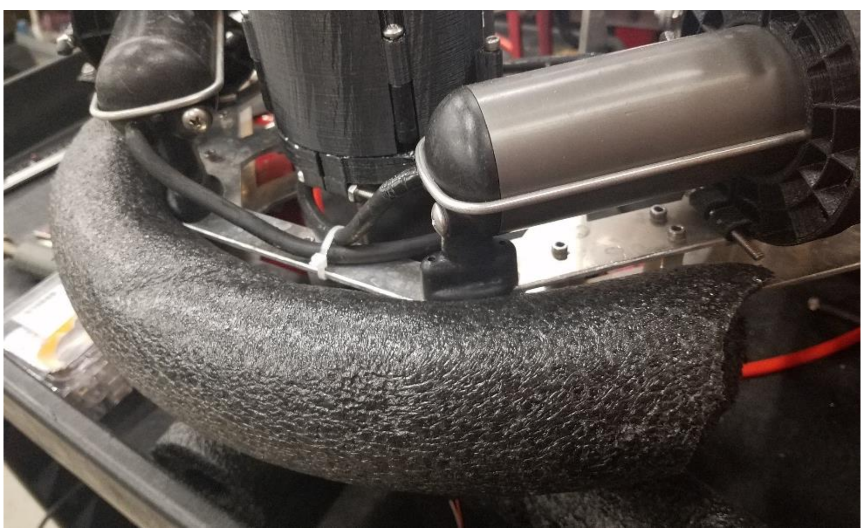


Figure 16 - Pool Noodle

The electrical system has been designed to reduce the possibilities for d The electrical system contains several fuses throughout the primary power paths. These are positioned and sized such that any power-related fault condition of the robot will blow these fuses. In addition

Accounting

Budget

Parts		
	Metal	$600
	General Hardware	$2300
	Electronics	$2100
	Reused hardware	$4100
Subtotal:		$9100
Competition:		$265
Travel:		$10000
Total:		$19365

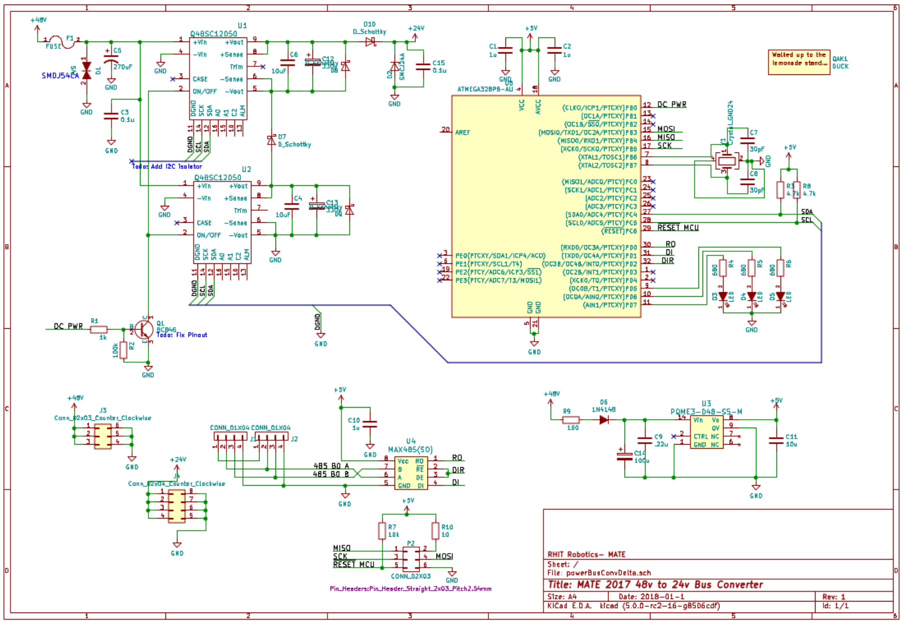
Cost Accounting

	From	**Description**	**Cost**	**Category**
Purchased Robot Hardware				
	McMaster Carr	Acryllic stock, hardware for small canister	$259.08	Stock Material
	Amazon	Odroid C2	$60	Electronics
	Digi-Key	Ferrites, filter caps, and misc for troubleshooting.	$30.25	Electronics
	Bay Area Circuits	Main and Motor controller circuit board	$73.65	Electronics
	Mouser	Humidity sensor	$18.40	Electronics
	Digi-Key	Components for board population	$201.03	Electronics
	Amazon	3D printer filament	$15	General Hardware
	Blue Robotics	Main Canister	$216.00	General Hardware
	Ebay	USB camera	$60.00	Electronics
	Amazon	Miscellaneous Hardware	$120.00	Electronics
	Digi-Key	Power Converters	$200.00	Electronics
	Ebay	Aluminum Bolts (Bulkhead Penetrators)	$26.00	Stock Material
	Ebay	Strain Relief	$33.00	General Hardware

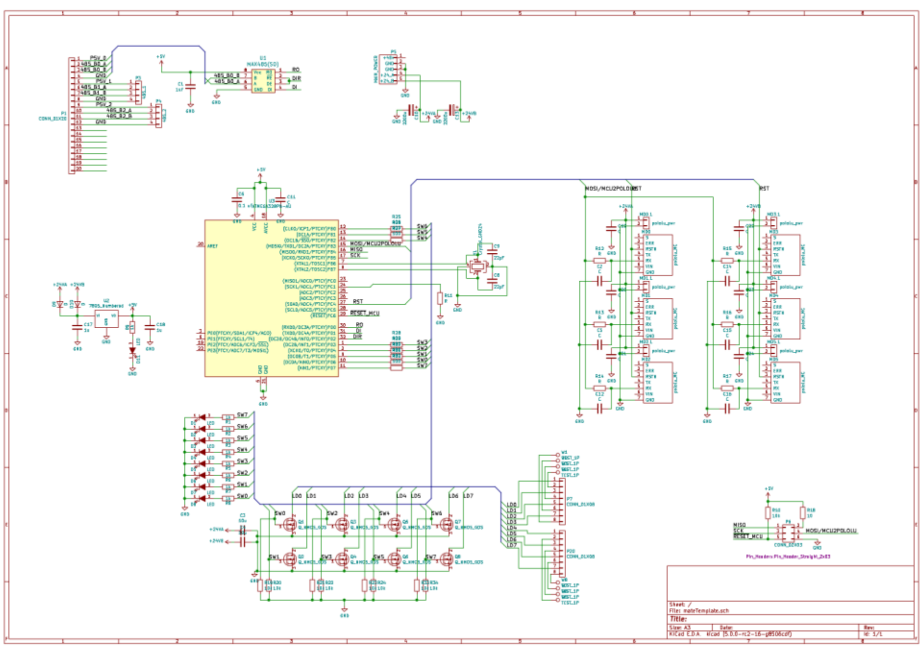
	Ebay	Thruster	$500.00	Electronics
	Ebay	Nylon Bolts	$16.00	General Hardware
	McArther	Ethernet Subconn	$600.00	Electronics
	Ebay	Solenoid	$16.00	Electronics
	Digi-key	Power board components	$160.00	Electronics
		SUBTOTAL	$2,604.41	
Reused Robot Hardware				
		5X Thruster	$3,500	
		Power Subconn	$600	
Travel				
		Competition Registration	$315	
		Airline Tickets	$2,932.46	
		Hotel stay	$2,240	
		Future Travel Expenses	$1,000	
		SUBTOTAL	$6,487.46	
		TOTAL	$13,191.87	

Appendix:

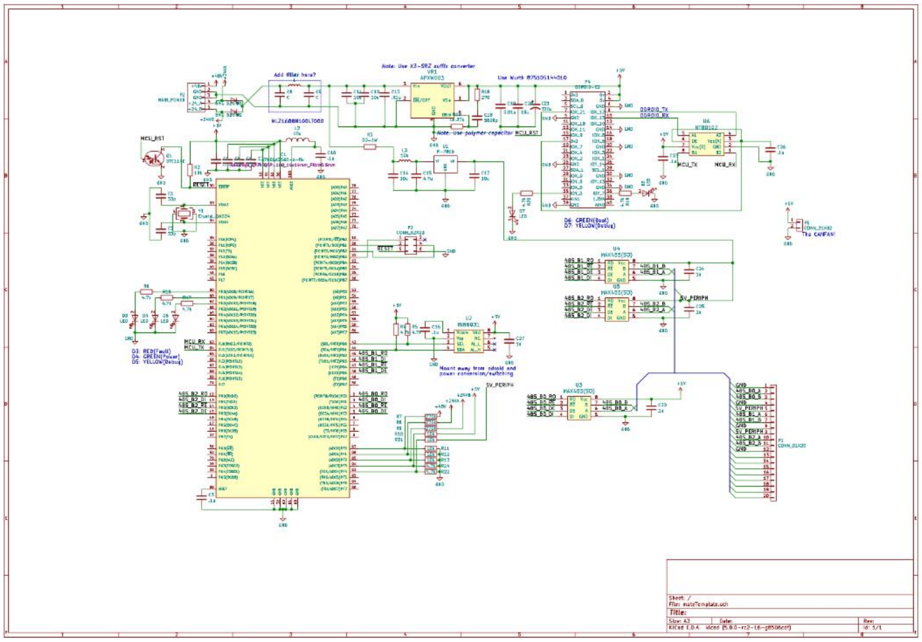
Power Conversion Board Schematic



Motor Control Board Schematic



Main Control Board Schematic



Acknowledgements

Rose-Hulman Ventures, for the use of their vacuum chamber and waterjet cutter.

The Branham Innovation Center supervisory staff, for being tolerant of our late work sessions and introduction of a large trough for early testing.

The Rose-Hulman Sports and Recreation Center lifeguards and staff, for allowing us to use their pool for testing and filming

References

"2018 MATE ROV Competition Manual, Explorer." Marine Advanced Technology Education, Nov. 2017.