MSOE Underwater Robotics

Milwaukee School of Engineering, Milwaukee, Wisconsin

The Systems and Design Philosophy of *Anchor*

May 2014 Final Report

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Prepared For:

Marine Advanced Technology Education

International ROV Competition

Abstract

MSOE Underwater Robotics was able to get its feet wet for the first time ever at the 2013 International Competition in Seattle, WA. After a year of hard work and learning, the team had a whole new understanding of ROVs and was prepared to dive into the new challenge this year's competition presented.

In order to address some of the interpersonal issues the team faced last year, the continuing members from 2013 devised a hiring process:

1. Gain interest on campus using student fairs and guest speakers
2. Contact potential members and give them an online application to gauge their interests, abilities, and potential
3. Review applications and select students for a brief interview
4. Select candidates for the team

The team decided to go with this approach because it is very similar to how professional companies look for employees. Thanks to this process, the 2014 MSOE ROV team is well-equipped with members who have diverse backgrounds in several fields.

Once the team was formed and introduced to the ROV world, work began on creating a new ROV that could handle anything thrown at it. This machine was built to accomplish the activities of the competition mission including observing ocean activity, mapping shipwrecks, retrieving debris, and replacing underwater sensors. Such a machine would require new ideas, new materials, and a lot of hard work.

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Design Rationale

Last year's ROV design left a lot of room for improvement, but also gave team members a foundation to build off of. Thankfully, the new team had a lot of new ideas and suggestions. Not wanting to completely reinvent the wheel, the team carefully analyzed the 2013 ROV. After this analysis, it was decided that the best course of action would be to start from scratch with the mindset of allowing new and better ideas to shine. While discussing and brainstorming ideas for the new ROV, the team made sure that the design would be sleek, efficient, well thought out, cost friendly, and reliable. With these thoughts in mind, the team would be able to design the ultimate piloting machine.

New Vs. Used Systems

Due to the overall unreliability of last year's ROV, almost every system was rethought out and redesigned. However, there was no need to be wasteful on the parts that were still functional and reliable. For example, the high efficiency DC/DC regulators were able to be reused. These regulators have never malfunctioned and still produce a clean, stable voltage even under significant loads. Additionally, the 23m of 6awg power wire was able to be salvaged as it is a high quality, marine grade wire that is designed to last many years of usage.

Commercial Systems

While many of our team members would have preferred to design every system from the ground up, this was not always possible or practical. Designing custom systems is resource intensive and time consuming, but allows for the ROV to have exactly what it needs. However, choosing a commercial solution often allows for acceptable and faster results. Due to limited time and human resources, commercial systems were occasionally sought out to allow team members to focus on other unique systems. Additionally, using some commercial systems helped introduce the team's future engineers to products and systems that are used by professionals in the field. This will provide them with knowledge that will be useful in years to come.

Frame

The frame is used to provide structure and mounting for every system on *Anchor* and is one of the most iconic parts of any ROV. Many revisions and designs were analyzed to find the most compact frame that would still be practical. Having a small, well designed, well thought out frame allows for better tool placement, better thruster flow, ease of entering the shipwreck, and better general maneuverability. Such a design is also aesthetically pleasing, professional in appearance, and will use less materials in construction.

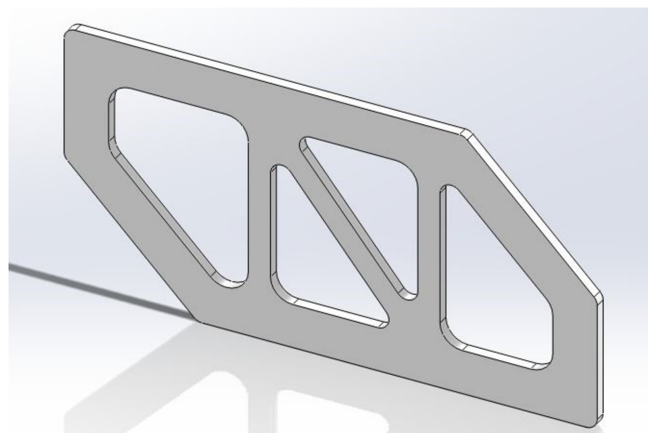


Figure 1—SolidWorks drawing of one frame piece

HDPE was chosen as the frame material due to it's strength, stiffness, and near neutral buoyancy (0.95g/cm3), all while still being incredibly easy to work with. After finalizing a design in SolidWorks, a 1.25cm sheet of HDPE was cut to shape using an on campus CNC machine. Using a CNC is more precise and more repeatable in comparison to machining the frame by hand.

Dry Housing

Last year, the team faced many issues with keeping the inside of the dry housing dry. Looking for a superior dry housing, the team researched several options online, from cylindrical to standard box designs. Eventually, the team settled on using a 12" x 10" x 6" IP68 enclosure from Attabox. Before risking *Anchor's* electronics, the IP68 rating was verified by submerging the Attabox in Lake Michigan, at a depth of approximately 10m for 1 hour. After this test, no water had entered the box.

Figure 2—12"x10"x6" IP68 Attabox Enclosure

This dry housing has a tinted clear lid that blocks harmful UV radiation that could damage the electronics when used outdoors in lakes, oceans, or pools. Its large size allows for neater electronics mounting that does not require several layers, which are clumsy to work with. Finally, the box has strong reinforced edges around the seal which stops water pressure from pushing the walls in and breaking the seal.

Thrusters

Designing and building custom brushless thrusters is not only a very enjoyable experience, but also allows for thrusters that can maximize the power provided. Moving quickly, in a stable manner, allows for mission critical tasks to be completed faster. This led the team to have ten 400W thrusters placed evenly around *Anchor*: 4 horizontal thrusters, 4 lift thrusters, and 2 lateral thrusters. As an added benefit, this system has built in redundancy that allows *Anchor* to continue performing even if one or several of the thrusters stop functioning properly. This is a failsafe that ensures we will be able to pilot the ROV even if a problem occurs.

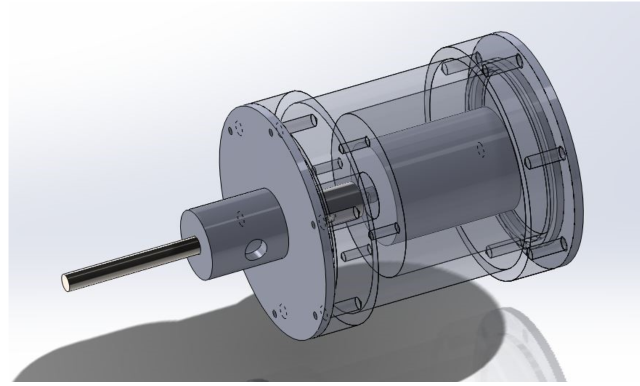


Figure 3—SolidWorks rendering of team designed motor housing and shaft seal

Mechanical Design

Previous thruster designs have suffered from poor sealing that have caused motors to rust and seize, forcing the team to rethink shaft seals. To keep the motor dry, a motor cap was designed to allow for a pressurized grease seal on the final stage of the 410 stainless steel shaft. This seal prevents water from entering the main cavity due to the high viscosity of the grease and the tight seals. Due to the foreseen difficulties in machining a cavity with a diameter bigger than the hole, these caps were 3D printed. Additionally, the main body of the thruster housing was CNC'd out of aluminum. Thanks to aluminum's excellent thermal properties, it provides an exceptional heat sink for the 400W motors. Keeping the motors cool, lowers resistance, increases efficiency, and increases motor life. Finally, by utilizing technology to manufacture the thrusters, they were created faster and hold tighter tolerances in comparison to being machined by hand.

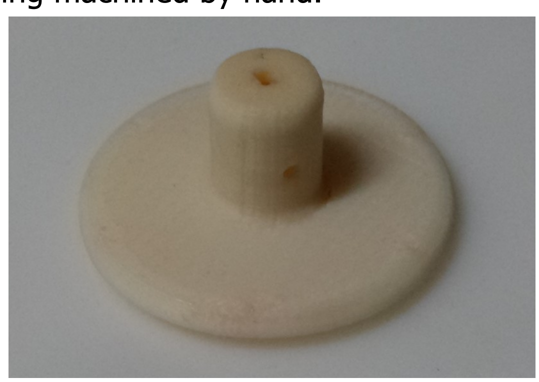


Figure 4—3D Printed motor housing cap

To maximize motor life from the lateral forces produced by the spinning propeller, the motor's shaft is laterally decoupled from the thruster shaft. This is accomplished by using a D-shaft on the motor and a mated piece on the thruster shaft. While allowing small lateral movement from the propeller, the D shape of the shaft locks rotational movement allowing the propellers to spin.

Electrical Design

Because each thruster needs 400W of electrical power at maximum thrust, it was critical to have electronics that could support this. After researching and testing the performance of several speed controllers, the team's Electrical Engineers decided to use Castle Creations' Mamba Micro Pro ESC (Electronic Speed Controller). This ESC has a quick response time, a simple RC servo interface, smooth acceleration, and is capable of handling 35A in air with no cooling. With a 12V electrical system, this means that each ESC can handle 420 watts without a problem, meeting the needs of the motors.

To provide maximum cooling and to have a simpler design, the ESCs were potted in PolyCast PC-282 two part epoxy. This is a thermally conductive, electrically isolating electronics potting epoxy. With heat sinks exposed to water, the ESCs will have superior thermal cooling giving them a longer life with better performance and lower resistance.

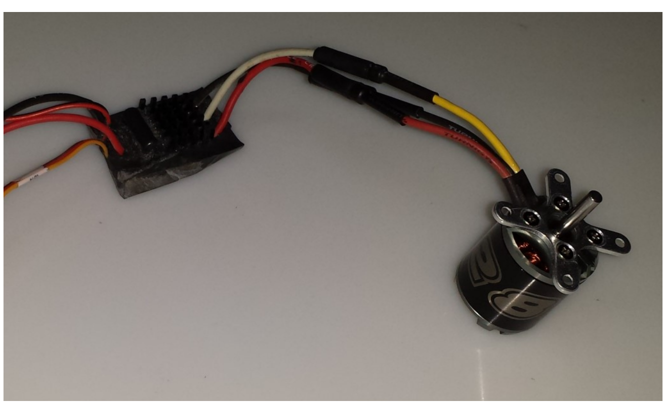


Figure 5—Potted CastleCreations speed controller and paired 400W brushless motor

Hydraulic Manipulator

Finding reliable, waterproof linear actuators has always been a challenge on past ROVs the team members have built. Wanting to explore something new, the team decided to use hydraulics for the first time ever.

To provide maximum amount of grip, the manipulator claws are machined out of two separate blocks of solid rubber. This rubber has a high coefficient of friction which vastly reduces the chance of dropping gripped items. Combined with a maximum gripping force of 650N, moving debris and replacing items during the mission has never been easier.

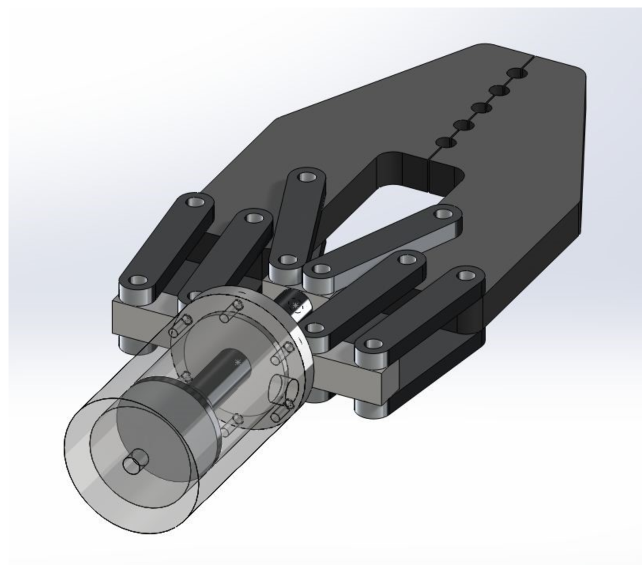


Figure 6—CAD drawing of team designed manipulator and hydraulic cylinder

Since water is always abundant wherever *Anchor* is used, it is also used as the hydraulic fluid. Such a setup allows for a lighter ROV, as no tank of hydraulic fluid needs to be kept on the ROV during transport. To pressurize the water so it can perform work, an enclosed RV water pump is used. Such a pump is capable of producing a max supply pressure of 345kpa. Additionally, this pump is electrically isolated from the water in its own enclosure

All hydraulic lines are properly rated to conform to MATEs strict safety specifications. Additionally, the team's custom designed and manufactured hydraulic cylinder was pressure tested by the UWM Freshwater Science Department and found to conform with the MATE specifications.

Agar Auger

Occasionally, researchers need to bring samples from the ocean floor to the surface for further testing. To take the sample from the microbial mat, an auger was designed in SolidWorks and then 3D printed. This auger was then mounted on a waterproof RC servo that was modified to rotate continuously. Usage is simple: just position the auger over the microbial mat, engage the servo, and let the auger drill into the sample. Once enough of the sample has been gathered, *Anchor* flies upward removing the auger from the microbial mat. The sample is contained in a plastic tube fixed around the auger. Then this sample can be brought to the surface for further evaluation by trained researchers.

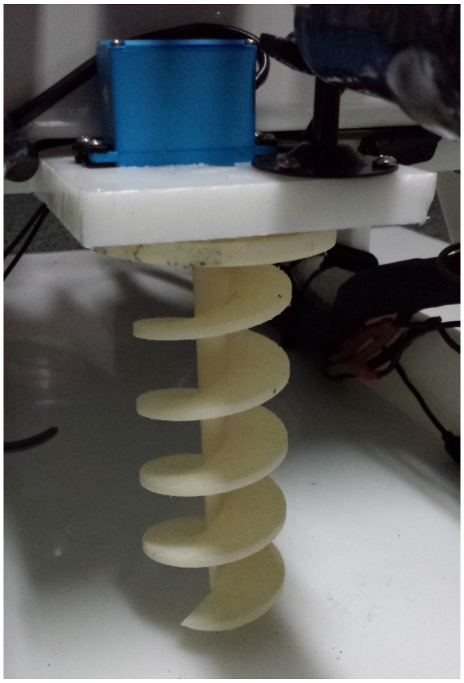


Figure 7—3D Printed agar auger

Buoyancy/Ballast

Buoyancy/ballast are crucial aspects that must be considered in order to build a stable ROV. It is critical to keep things that are less dense than water near the top of *Anchor* and things that are more dense than water near the bottom. This lowers the center of gravity on *Anchor* and helps keep it upright in the water. However, it also needs to be balanced properly to stay neutrally buoyant. Having a neutral buoyancy allows the pilot to focus more on the mission and less on holding the ROV in a certain position.

Figure 8—Lead Diving weights for ballast

The main dry housing is the primary source of buoyancy and is located in the center of the frame, as high as it can be. To counteract the large amount of buoyant force produced by the dry housing, lead diving weights are placed at the bottom of the frame.

Tether

All electrical power and data must be transferred through the tether, making it a critical lifeline to *Anchor*. To transmit the given 1920W of electrical power, 23m of 6 awg marine grade wire is used. This wire is resistant to UV damage and corrosion, while still being surprisingly flexible. At full load of 40A, there is a minimal voltage drop of 2.5V resulting in a 5% loss of power. This was deemed acceptable as thicker wire gauges are heavier, more expensive, and less flexible.

Wanting nothing but the best for communications, 25m of Cat7 ethernet cable are used. This cable provides superior electrical shielding, as it has shielding around each of the twisted pairs and around the entire cable. The shielding allows for faster data transfer rates in harsher environments allowing for a superior medium for data transfer.

Strain relief and portability are critical in having a useful tether. To provide strain relief to the tether and to prevent the main power and communications bulkhead from pulling, a wire mesh grip is used. This device is strikingly similar to a Chinese finger trap toy, in that it grips the bundled wires tighter as more force is applied. Thanks to the SubConn bulkheads, the tether is also easily detachable. Detaching the tether allows for easier transportation as the weight of the ROV system can be split amongst more team members and is therefore less bulky.

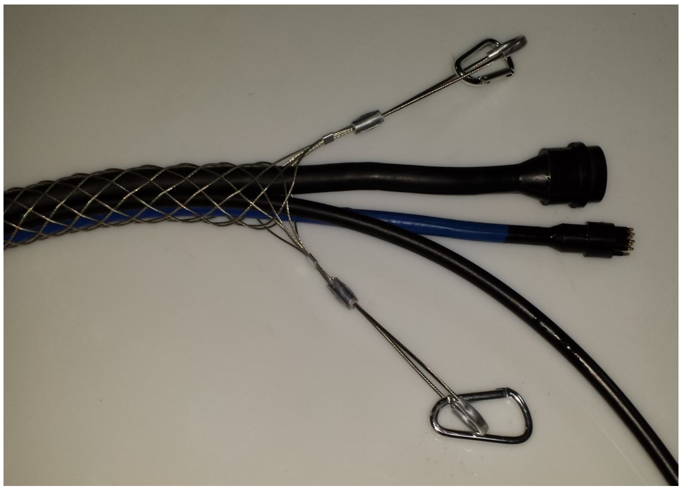


Figure 9—Detachable tether with wire support grip and removable bulkheads

Electrical System

Power

To keep up with the large power demands of the 12V, 400W thrusters, many power electronics are needed. To get such a large amount of 12V power from the supplied 48V, three banks of 700W DC/DC regulators are used. These regulators run with an efficiency of 91%, stay fairly cool, and have lots of protective circuitry built in (overvoltage, overcurrent, thermal shutdown, slow start, and short circuit protection). To properly distribute this large amount of power, two 1cm x 2.5cm bars of aluminum are used as busbars. All power connections are done through this to allow for organized wiring and secure connections.

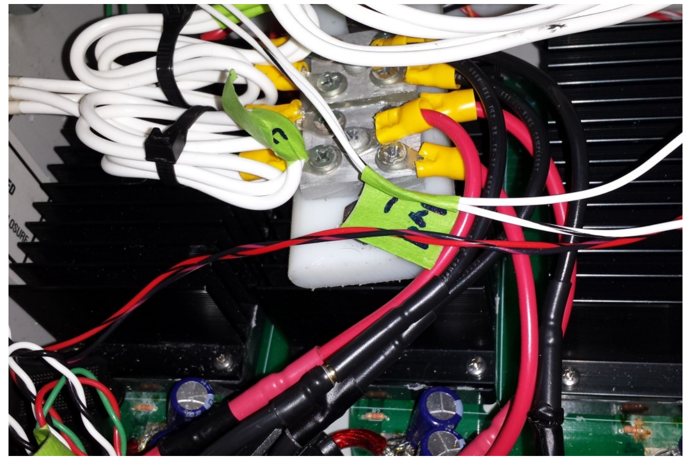


Figure 10– Electrical busbars and bank of 48V->12V DC/DC regulators

Control Electronics

All systems on *Anchor* are kept as simple as possible to reduce the chance of something failing. To control motors, an Arduino Due is used to read and process the UDP Ethernet stream sent from the PC. Then, it sends motor controller commands to the electronic speed controllers (ESCs) and servo motors. The Arduino Due has a large amount of I/O and many other attributes for interfacing with the world. It features an 84MHz, 32bit processor that is capable of processing any of the commands that might be sent to it today or in the future. This microcontroller is also readily available and has lots of open source libraries. This helps reduce development time and increase the amount of time that can be focused on brainstorming and troubleshooting the system on *Anchor.*

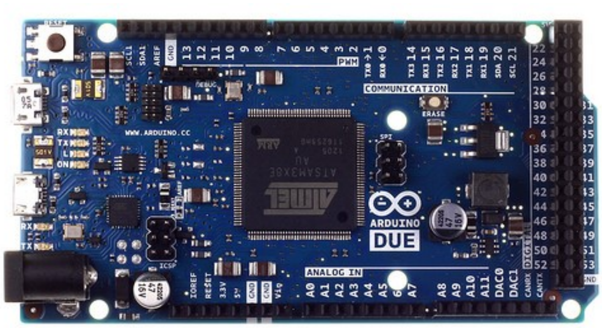
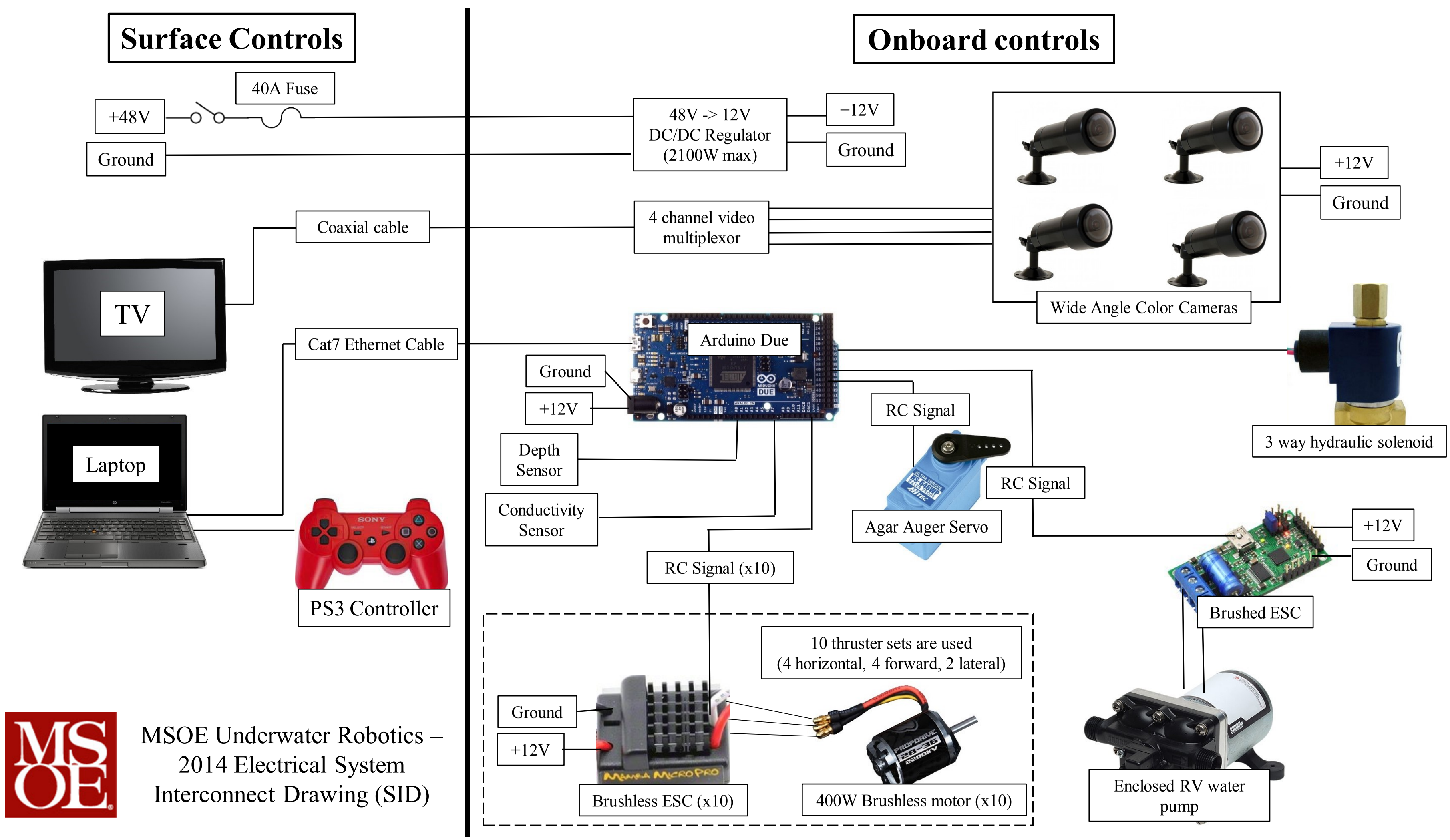
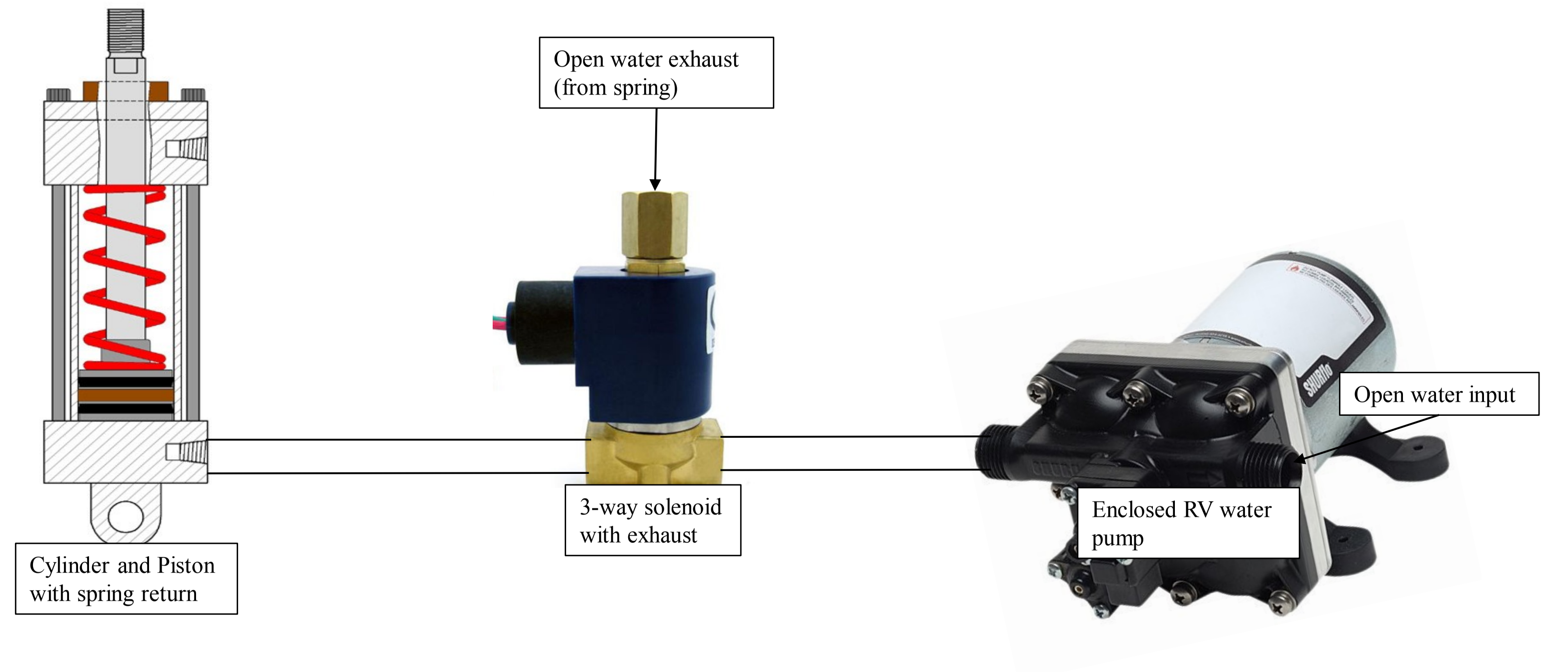


Figure 11—32bit Arduino Due Microcontroller


Surface Controls
Onboard controls
+48V
40A Fuse
Ground
48V -> 12V DC/DC Regulator (2100W max)
+12V
Ground
Coaxial cable
4 channel video multiplexor
Wide Angle Color Cameras
+12V
Ground
TV
Cat7 Ethernet Cable
Arduino Due
Laptop
PS3 Controller
Ground
+12V
Depth Sensor
Conductivity Sensor
RC Signal
Agar Auger Servo
RC Signal
3 way hydraulic solenoid
RC Signal (x10)
+12V
Ground
Brushed ESC
10 thruster sets are used (4 horizontal, 4 forward, 2 lateral)
Ground
+12V
Brushless ESC (x10)
400W Brushless motor (x10)
Enclosed RV water pump
MSOE Underwater Robotics – 2014 Electrical System Interconnect Drawing (SID)



MSOE Underwater Robotics –
2014 Fluid Power System
Interconnect Drawing (SID)

Wiring

Wiring neatness is an ongoing battle and is critical to keeping the electronics workable and debuggable in case something goes wrong. We wanted to have quick and easy access to every area in the dry housing. Therefore, structured organization within the space was a must. To accomplish this, wire runs are made logically and extra wire is zip tied to itself, so the wires do not get tangled. Whenever possible, wires are either color coded (red for 12V, black for ground, etc.) or labeled for safety. Additionally, there are no layers used and instead everything is either mounted on the bottom or the walls of the dry housing. This allows team members to have access to all of the wires without having to remove shelves, which was required in past years.

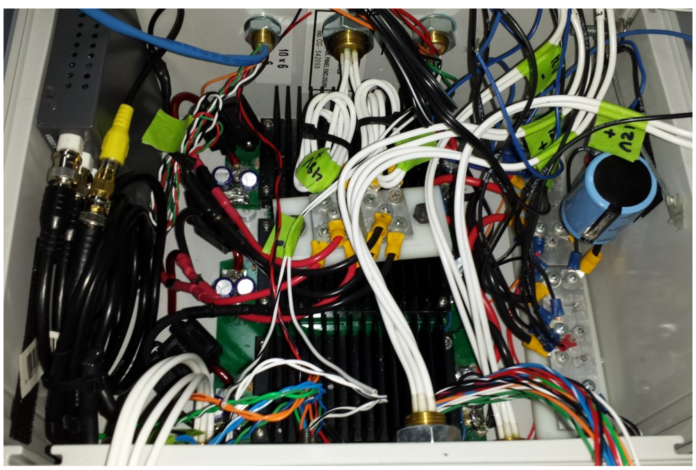


Figure 12—Initial attempt at wire organization

Bulkheads

Bulkheads allow for electrical signals and power to go in and out of the main dry housing. They also allow for the ability to detach systems from the ROV, such as a thruster, camera, or the tether. Previous attempts have been made to design custom bulkheads out of PVC, epoxy, and wire. While these bulkheads worked initially in shallow water, they ultimately failed when exposed to depths around 5m.

Figure 13—Several SubConn bulkheads securely mounted to the main dry housing

Not wanting to waste more time or resources building and testing a custom bulkhead solution, it was decided that a commercial system was the next best option. After much discussion and planning with SubConn, producers of one of the best bulkheads in the world, a selection of nine bulkheads were chosen. Five of these bulkheads are rated for high currents (50 amps), and are useful for high power thrusters and bringing in the main power. Three bulkheads are for lower devices (LEDs, sensors, cameras, etc.) and have the largest pin count. One bulkhead is used for medium power devices (servos, hydraulic pump, solenoids, etc). The remaining bulkhead has special shielding for Ethernet, along with 4 wires for camera signals.

By utilizing this commercial resource, *Anchor* becomes more reliable because the SubConn bulkheads will never leak and more time can be spent on perfecting other systems of *Anchor*. Additionally, bulkheads like these are standard in the marine industry, so they expose the team's engineering students to standard products used in the field, which better prepares them for a job designing marine robotics projects.

Sensors

Instant feedback is critical to having a robot that is useful in real life applications. Without any sensor feedback, the pilot and researchers have no idea what is actually happening around *Anchor*. To accommodate this, a wide variety of sensors have been chosen.

Measuring Device

To obtain a quantitative measurement of how big or small things in the ocean are, a measuring system is necessary. Initially, the team wanted to use a laser rangefinder to measure distances as it would be fast and reliable; however, the items we need to measure have few points that can be used with a laser. As a result, a simple tape measure with a camera and hook is used. To operate: attach the hook to an object, pull the tape measure with *Anchor*, and observe the measurement.

Conductivity Sensor

Water conductivity is an important measurement for researchers as it is used to determine how much salt and other minerals are in the water. To sense conductivity in the water, a very precise sensor is used from Atlas Scientific. This sensor has platinum wire, is intended to be submerged in water for extended periods of time, and is corrosion resistant.

Figure 14—Conductivity Sensor

Vision

Without cameras, *Anchor* would be blind in the water. Cameras provide a low latency, visual feedback system for the pilot to use to navigate through shipwrecks and complete other tasks. To get this feedback, five bullet style security cameras were waterproofed using heat shrink and a thermoplastic adhesive. These cameras have 700 vertical lines of resolution, excellent low light properties, and low distortion 170 degree wide angle lenses. With the five cameras strategically placed around *Anchor,* blind spots are greatly reduced and a full view around the ROV is possible.

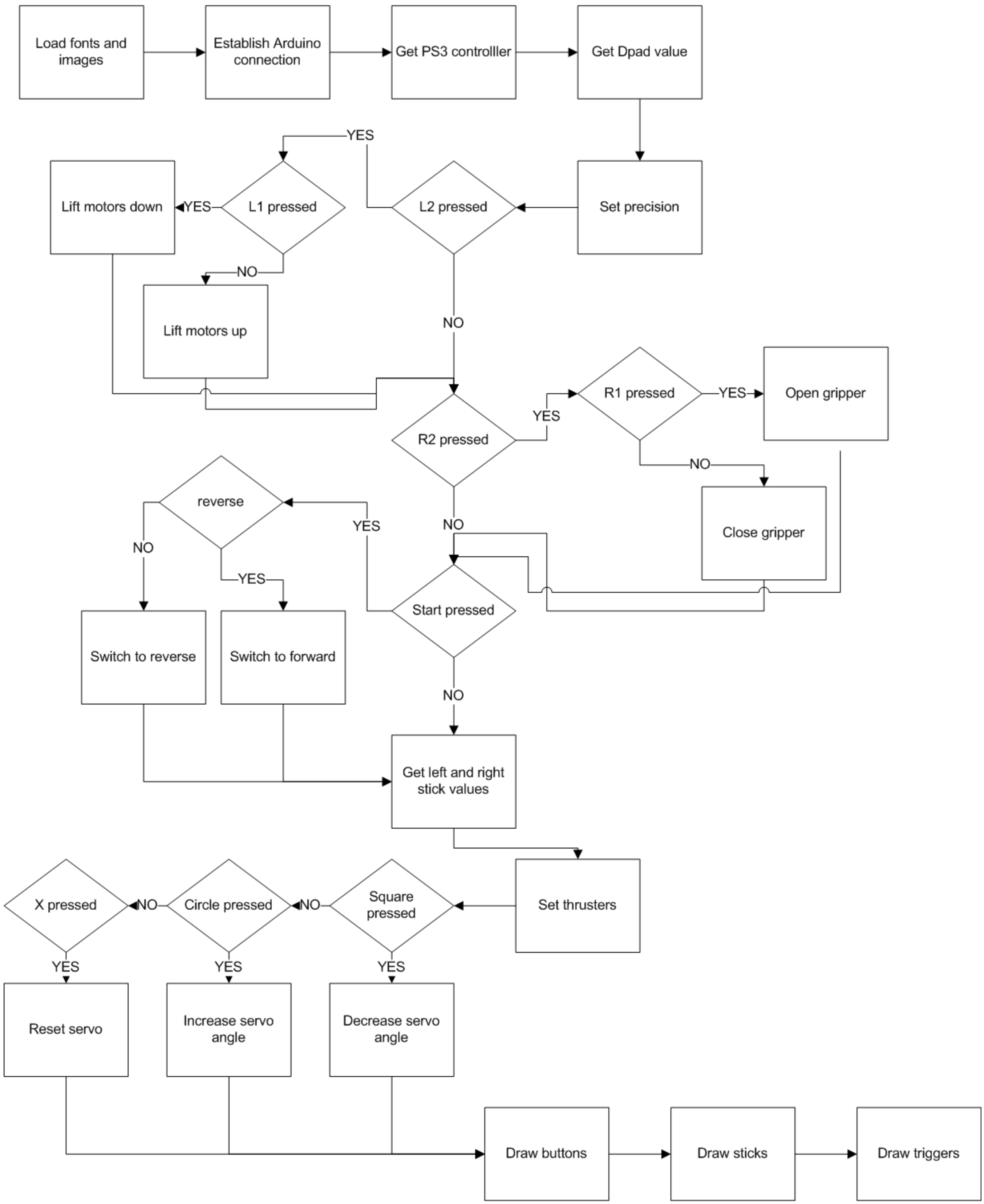
Figure 15—700TVL camera with 170 degree wide angle camera lens

Software

A software system allows for greater flexibility when compared to a pure hardware system. Values are only a few lines of typing away from being altered, redefined, or adjusted as needed. The main application used was team written in Processing, a java based framework. This software reads in values from a PlayStation 3 controller and then processes and sends them over an Ethernet stream to a microcontroller located on *Anchor*.

Software Flowchart

Laptop/Processing flowchart



Communication

Last year, the team's ultimate issue at the competition was not being able to communicate with the ROV to operate motors. As a result, a more robust communication method was necessary. After weeks of discussion, research, and comparison of different communication methods, the team decided it would be best to use an ethernet based communication. Ethernet is used by personal computers, factory equipment, and PLCs.

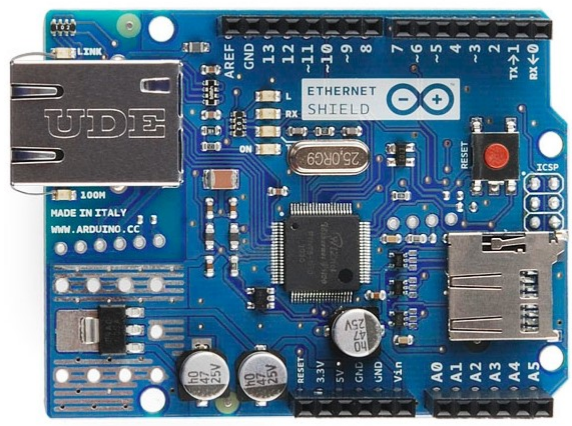


Figure 16—Arduino Ethernet shield used for UDP communication

Once a robust transmission medium was decided on, a protocol was needed to exchange data between the PC and *Anchor*'s motor controllers. To transfer the data, the values to be sent to the motors are converted to an ASCII encoded, comma separated string. This string is then transmitted to *Anchor* using a UDP datagram packet. While UDP provides no guarantee of the message arriving at the destination, it is faster than TCP and has a much lower latency. The lower latency of UDP helps increase ROV response time to help complete tasks faster, and since the PC is constantly sending new strings to the ROV, losing one of these every now and then is simply not noticeable in real life.

Safety

Safety has been a main focus throughout the building and testing phases of *Anchor*. The team has a zero-tolerance policy for unsafe practices or materials. Because of this philosophy, the team made sure to install the proper warning labels on *Anchor*. Electrically, each motor controller has a current limiting feature to prevent damage to the motors that could overheat. To prevent arcing when attaching power, a main power switch is used inline with the tether. Each bulkhead used has a margin of safety with its current rating to prevent overheating and component damage. To avoid accidents resulting from electrical shock, power is always turned off and capacitors are allowed to safely discharge before tools or hands are allowed in the main electrical dry housing. By following these strict safety guidelines, the team is happy to report a 100.0% incident free work environment.

Challenges

Technical

When designing the thrusters, a motor cap was necessary to seal the shaft. We created a well thought out design of a cap that would function as we needed it to. While we had come up with an excellent design, we realized that manufacturing it would be extraordinarily difficult due to the large cavity inside the small hole. After several brainstorming sessions on how to rework the design or how to possibly machine it, the team discovered a solution. The answer to this problem was to 3D print the motor caps using a special printer capable of printing both a structural plastic and a dissolvable filler plastic. Going through with this idea produced a high quality motor cap that otherwise would have been impossible to create.

Interpersonal

The team this year worked extremely well together. There were some hurdles we had to overcome, but overall, the team was very satisfied with how members interacted. One challenge the team faced was due to a member not completing his work. The member had several tasks assigned to him which were left uncompleted. This member consistently told other teammates that he would get to them, but never made any actual progress. Eventually, the team had to delegate the tasks to other members when this person stopped communicating with the rest of the team. The team was forced to complete these tasks last minute and gave other members additional work that they were not prepared for. The team handled this challenge very well. Each member took on something new and the tasks were completed on time.

Lessons Learned

Technical

3D printers can be an incredibly valuable asset to a team that needs custom parts machined in a timely manner. We learned that a 3D printer can be harnessed to create complex shapes that would be difficult or impossible to machine using traditional milling or turning techniques. This forced the team to become familiar with how a 3D printer operates and to understand the physical limitations and abilities of the printer. Several things learned with this were: some 3D printers require a filler material to support structures printed above, precision is not always the best but can often be worked around, and 3D printed pieces have a grain that needs to be set to provide the best mechanical properties. Many hours were spent testing and learning these aspects and will be even more valuable in the years to come.

Figure 17—Makerbot Replicator 2X used for printing custom parts for the ROV

Interpersonal

The biggest lesson that the team learned this year was that the most important part of creating a good team is picking the right members. Since the team incorporated a more thorough review of candidates before choosing members, the team was able to select members that worked well with each other. This allowed for a more enjoyable experience for all of the members.

Trouble Shooting Techniques

Due to the problems the ROV team had last year, the team decided to implement a more stringent troubleshooting process. Because the ROV is so delicate and intricate in nature, it was extremely important to be able to solve problems in a consistent and logical way. In an effort to be prepared, the team created a troubleshooting plan to use when issues arose. This plan carried over from the previous year. The plan included writing down the issue, brainstorming possible solutions, discussing the pros and cons of each choice, choosing the best option, and finally implementing the new idea. If the team still had issues after the newest iteration was implemented, the process began again. This process was completed as many times as necessary to find the best solutions possible. The team hoped to find the best solution the first time, but experience has shown that this is not always the case.

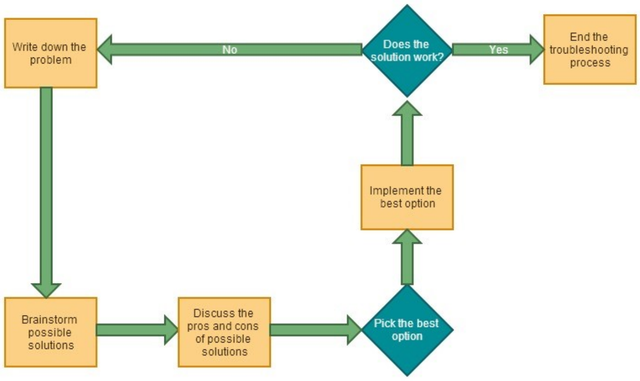


Figure 18—Flowchart showing the team's trouble-shooting technique

Future Improvement

Every project can always be improved, no matter how good it might be. In the future, a 3D stereoscopic camera setup could help the pilot get a better feel for depth perception in the water, which would help complete tasks faster. Additionally, while having a lot of powerful thrusters is a lot of fun, the ROV could potentially be better off with a single thruster that can vector the thrust in any direction. Such a thruster would allow for faster maneuvering and more precise positional control, both of which are critical for an ROV's performance.

Reflections

"Watching the team grow from last year to this year has been extremely rewarding. The process of building an ROV has helped me grasp the bigger picture of a project, while helping me lead a group. I have also learned valuable real-life debugging and troubleshooting skills that are helpful in many other parts of my life."

~ Seth Opgenorth, CEO

"Joining the MSOE ROV team was one of the best choices I've made when it comes to professional development. The work I did for the team this year helped me to learn how to manage my time effectively when working on projects over a long period of time.The team allowed me to combine something I enjoy, writing, with professional quality work. I've strived to do my best with the work I've done, and I hope to be able to use the skills and experience gained in the future as a technical writer."

~ Austin Liebler, Technical Writer

Teamwork

Building a complex vehicle, like an ROV, is not possible without the help of a team of dedicated individuals. Every system on the ROV had a set time frame for completion of system specific goals, and a specialist (team member) was assigned to each system. Without a schedule or deadline to go by, team members would not know when their work was due and would likely procrastinate on their assigned tasks for the team. Unfortunately, due to the busy lives of the college students on the team, these deadlines were often too optimistic and as result had to be extended. Fortunately, extra time was built into the schedule in case other events occurred. In the end, we were able to accomplish all of our goals, and every single system on the ROV was chosen, designed, and/or built by the team's members. Additionally, the entire ROV along with all of its components have been tested many times.

Figure 19—Team logo

Pictures of *Anchor* the ROV

Figure 20—Complete, intact ROV that is ready for water

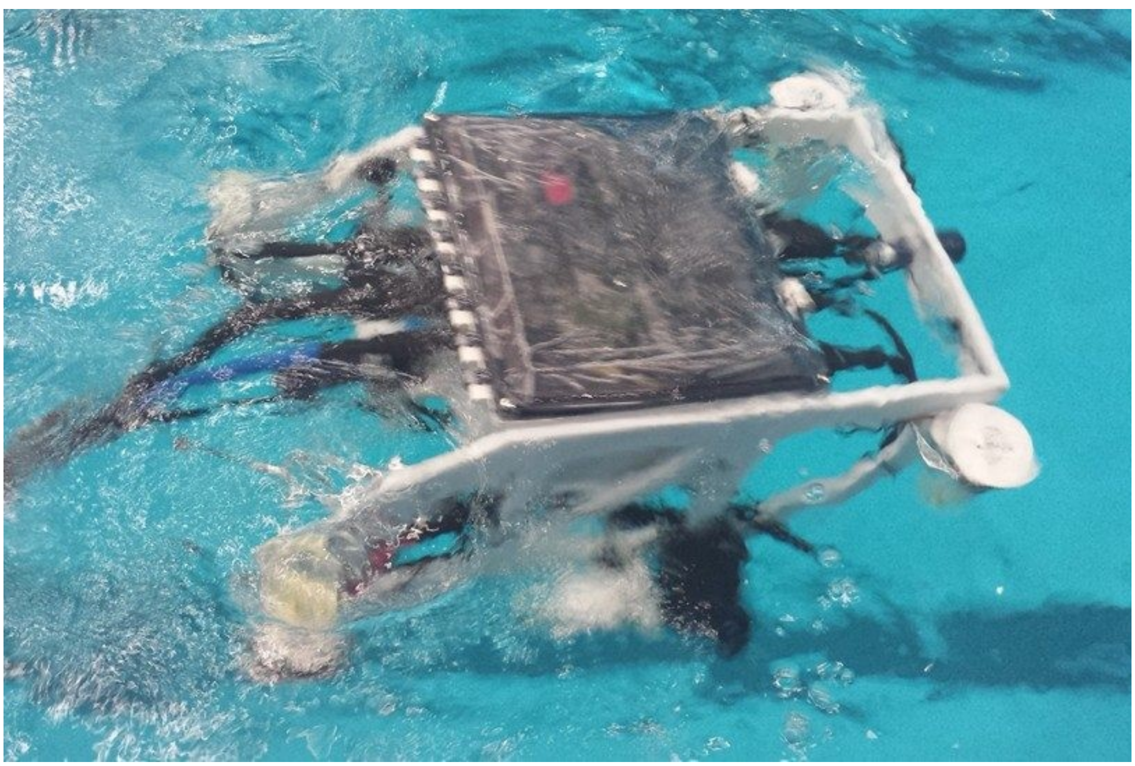


Figure 21—Complete, intact ROV practicing mission task in a pool

Table of Controls for PS3 Controller

Button	Function
Left Joy Stick (up/down)*	Left thrusters
Right Joy Stick (up/down)*	Right thrusters
L1*	Lift Motors (upward)
L2*	Lift Motors (downward)
X	Gripper open
O	Gripper close
Left Joy Stick (left)	Lateral thruster (left)
Left Joy Stick (right)	Lateral thruster (right)
D-pad up	100% thrust
D-pad right	75% thrust
D-pad left	50% thrust
D-pad down	25% thrust
Start	Reverse thrusters

**analog input device*

Figure 22—Credit: Sony Corporation

Budget/Expense Sheet

Material/Service Expenses

Item	Quantity	Cost to Team	Fair Market Value	
100ft Cat7 cable	1	$24.81	$24.81	Purchased
23m of 6awg wire	2	$0.00	$300.00	Reused
Arduino Due	1	$43.01	$43.01	Purchased
Arduino Ethernet Shield	1	$31.95	$31.95	Purchased
Attabox 12x10x6 Enclosure	1	$13.67	$114.00	Only paid for shipping
Batteries	4	$0.00	$400.00	Reused
Brushless motors	10	$181.66	$181.66	Purchased
Cable ties		$20.00	$20.00	Purchased
Castle Creations speed controllers	10	$643.46	$899.90	Purchased at discount
CNC machining time		$0.00	$500.00	Donation of CNC time
DC/DC Regulators	3	$0.00	$1,200.00	Reused
HDPE sheet (4'x4')	1	$0.00	$160.00	Donation
Hitec Waterproof Servo	1	$60.00	$60.00	Purchased
Hot glue		$20.00	$20.00	Purchased
Laptop		$0.00	$1,200.00	Used team member's PCs
Propellers	30	$28.76	$28.76	Purchased
PS3 Controller	1	$39.99	$39.99	Purchased
RTV silicone	1	$8.00	$8.00	Purchased
Rubber block	1	$25.80	$25.80	Purchased
RV water pump	1	$70.39	$70.39	Purchased
Security Cameras	5	$523.10	$523.10	Purchased
Solenoid	1	$28.75	$28.75	Purchased
Stock aluminum		$120.18	$120.18	Purchased
SubConn Bulkheads	9	$1,000.00	$3,518.46	Purchased at discount
Wire and heat shrink		$121.55	$121.55	Purchased
	Total	**$3,005.08**	**$9,640.31**	
	Grand Total (Fair Market Value of *Anchor*)			**$9,640.31**

Travel Expenses

Item	Description	Total Cost to Team	Fair Market Value
Travel to Competition	Estimated gas cost	$350.00	$350.00
Rooms at Competition	Estimated hotel cost	$872.00	$872.00
		Grand Total	**$1,222.00**

Monetary Contributions/Fundraising

Description	Amount
Midwest ROV, LLC	$2,000.00
CITO	$1,000.00
Candy Bar Fundraiser	$200.00
2013 Engineering Presentation Prize	$100.00
Grand Total	**$3,300.00**

Summary

Total Material Donations/Discounts	$6,635.23
Total Cash Revenues	$3,300.00
Total Material Expenditures	($3,005.08)
Total Travel Expenditures	($1,222.00)
Ending Cash Balance	**($927.08)****

**Note: At publication of this document, potential sponsors are still being actively contacted

Acknowledgements

Attabox—Donation of IP68 dry housing

CITO—Monetary donation

Concourse BMW—Batteries for practice

Kohler Company—Donation of HDPE

MATE—Hosting a terrific competition and for being a great resource

Midwest ROV, LLC—Technical support and monetary donation

MSOE—For providing excellent facilities and faculty mentors/advisors

Mahuta Tool—Donation of CNC time

MacArtney/SubConn—For providing an exceptional discount on bulkhead connectors

TDK-Lambda—Donation of 3 DC/DC regulators

UWM Freshwater Science—For technical support and use of facilities

Jacob Dulmes—Delivering HDPE sheet

The Enea Family—For letting the team take over their basement for months on end

Thank you to our Faculty Advisor, Dr. Darrin Rothe, for guiding and supporting us throughout this project. Last but certainly not least, we would like to thank our families for providing us with moral support and for their willingness to help us in any way possible!

Safety Checklist

	Required Action
	Put on safety glasses
	Make sure dry housing latches are engaged and screws properly torqued
	Ensure all wires, motors, propellers, and materials are securely fastened
	Double check tether's strain relief connection to the ROV
	Check that there are no exposed sharp edges on the ROV
	Ensure that motor guards are in place and are guarding the propellers
	Verify that all hydraulic hose connections are secure
	Make sure that bare wires are not exposed
	Uncoil tether
	Check that 40 amp fuse is in place
	Double check the point of attachment to power source
	Double check the point of attachment to ROV

References

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