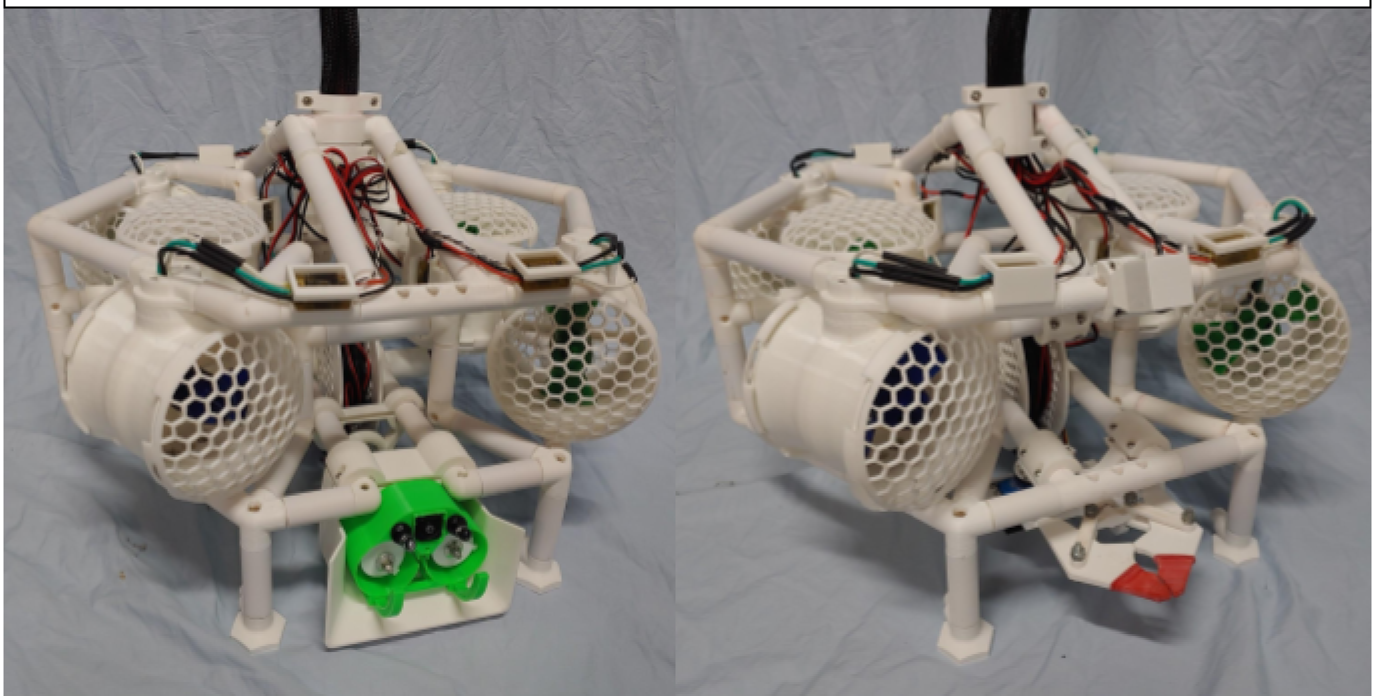
DEEP OCEAN ROBOTICS

Private enterprise based in Alvin, TX

2020-2021



Team Members

Executive Director (CEO):	James Blaine
Director of Finances:	Elis Karcini
Director of Safety:	Olivia Freeman
Director of Marketing and Documentation:	Lilly McDonald
Director of Programming:	Nathaniel Kinonen
Director of MiniROV Operations:	Shawn Steakley

Consultants (Mentors)

Matthew Steakley | Corbett Freeman | Robert Blaine

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Abstract

Deep Ocean Robotics is a small enterprise based in Alvin, TX. For the Marine Advanced Technology Education's Request for Proposal (RFP) for the 2020-2021 season DOR designed the Hexagonal Environmental Conditions Surveyor (HECS). This Remotely Operated Vehicle (ROV) has been designed to complete the specific tasks of the RFP, while staying within the guidelines.

DOR is an enterprise devoted to excellence and discovery. Throughout the season the company has been determined to improve both our ROV and our knowledge of mechanics, design, and the environment. We have greatly improved over last season in mobility, speed, reliability, underwater visibility, and both our design process and project management. Through Covid-19 and many of our staff leaving the company, DOR has remained motivated to reach our full potential, and exceed last season's accomplishments. We all feel that MATE has been a very educational, memorable, and important part of our lives and we will use what we learned for the rest of our careers.

Company Introduction

Deep Ocean Robotics is a small enterprise of primarily homeschooled students in the United States and Europe. The company had its beginning in 2018, when our staff member Shawn Steakley and Consultant Matthew Steakley volunteered at a regional MATE tournament and decided to found DOR the next year. During the first season, Deep Ocean Robotics grew from a group of Texans from the Houston area with few pre-existing relationships to a cohesive company that progressed to the International Competition. Since then DOR has expanded and now boasts members in the United States' Florida and in the European country of Albania. The primary goal as a company is to provide an enjoyable and helpful environment for learning and competition. Safety is a top priority both inside and outside of meetings. During the first surge of COVID-19, our team collaborated with a local network of makers to print and distribute over 700 face-shields and mask clips to local hospitals, nursing homes, and other groups in need. Over the course of this last season, many staff members became busy with college courses or had to leave entirely, resulting in the company being composed of six members, only four of whom are local. While sad for the loss of friends, Deep Ocean Robotics continues to pursue standards of excellence and safety while encouraging the staff's shared love of technology.

Figure 1.0 A shipment of face-shield frames printed by DOR

Environmental Responsibility

DOR understands the responsibility to the environment we have to take on. We decided the biggest area we could reduce our environmental impact is in reducing our plastic waste. Our ROV has three different types of plastic used in its construction. Polylactic Acid or PLA is a thermoplastic polymer and is derived from naturally renewable sources unlike plastics that come from petroleum. This makes it a biodegradable plastic (Rogers). Polyethylene terephthalate glycol or PETG is a highly durable plastic that can easily be recycled. Polyvinyl Chloride or PVC is a well known plastic that is also easily recyclable (General Kinematics). DOR has also reduced plastic waste by fabricating all of our 3D-printed parts locally, reducing the environmental impacts of shipping.

Company Staff

Executive Director (CEO): James Blaine

James Blaine lives in Texas and is a freshman attending Texas A&M University and majoring in mechanical engineering. He participates in a student organization at TAMU called AggieSat Lab, a satellite design group currently developing a cube-sat. James has acted as the Director of the Mechanical Department for Deep Ocean Robotics and has been the lead CAD designer for much of the HECS's design, and upon our initial Executive Director stepping down, naturally stepped into the position.

Director of Finances: Elis Karcini

Elis Karcini is from Albania. He is a senior at Bota e Diturise High School in Albania and will be attending Eastern Florida State College this fall. Joining Deep Ocean Robotics during his exchange year in the U.S. was his first involvement in robotics and programming. He claims the experience taught him much and expanded his interest in the STEM field. Though he returned to Albania early in 2020, he continued contributing to HECS's progress. Math has always intrigued him so he has taken part in national math competitions every year and is currently in a Coding Bootcamp to expand his knowledge in the field of programming.

Director of Safety: Olivia Freeman

Olivia Freeman is a Freshman in college attending the University of Houston Clear Lake. She is in their Mechanical Engineering program and wants to go into robotics. Olivia has been interested in robotics since eighth grade. She has taken part in FLL and FTC robotics competitions and has been a part of DOR for three years. This season she has been responsible for wire management and safety.

Director of Marketing and Documentation: Lilly McDonald

Lilly McDonald is a junior in high school. She currently attends classes at Homeschool Education Partnership and Bay Area Homeschool Academy. Lilly has always been interested in robotics and has participated in multiple leagues since sixth grade, first experiencing MATE when she joined DOR three years ago.

Director of Programming: Nathaniel Kinonen

Nathaniel Kinonen is currently a junior in high school in the Houston area of Texas. He has several years of experience as a programmer and computer enthusiast prior to working with Deep Ocean Robotics. He claims that, although he joined with some software knowledge, DOR has taught him much regarding the firmware and hardware related aspects of designing robots.

Director of SRT Operations: Shawn Steakley

Shawn Steakley is a robotics student of 9 years who has participated with successful teams in EARLY, Ecobot, and FIRST robotics. He recently moved to Florida to begin dual credit classes at Florida Tech, and will be attending there next year as part of the Honors College, striving for a Bachelor's Degree in Electrical Engineering. He began this season as the Executive Director of DOR, though upon his changing locations saw fit to step down.

Consultants

Matthew Steakley

Mr. Steakley has been a robotics coach for the past 9 years, competing in Early Robotics, ECOBot, First Lego League, First Tech Challenge, and MATE ROV. He has 30 years of experience in the Pipeline Automation Industry working with Pipeline Control System and is the current Product Manager for a new Suite of Liquid Pipeline applications for Open Systems International, Inc.

Corbett Freeman

Mr. Freeman has 25 years of engineering experience in structures, hydrostatics, materials, and inspection. He is currently on the management team for a Texas-based engineering firm, using his expertise in project management to advise DOR members in working toward completion of tasks and decision-making processes. Some of his past robotics mentorships include FLL, FIRST, and a previous year of MATE.

Robert Blaine

Mr. Blaine has worked as an Aerospace/Mechanical Design Engineer with NASA for over 20 years. He would like to say that mentoring the students of Deep Ocean Robotics has been a rewarding experience where he has been able to pass on some of his knowledge and gain some from them in return. Mr. Blaine provided access to the mechanical shop used as the company's work area for the majority of the season as well as the pool used for testing.

Mechanical Review

Structure (Fig. 2.0)

After finding difficulty in the basic rectangular design of our previous ROV, we chose a layered hexagonal frame for HECS. This shape was chosen to provide improved control over the vehicle's direction and depth, more space to mount components, and an overall more versatile form.

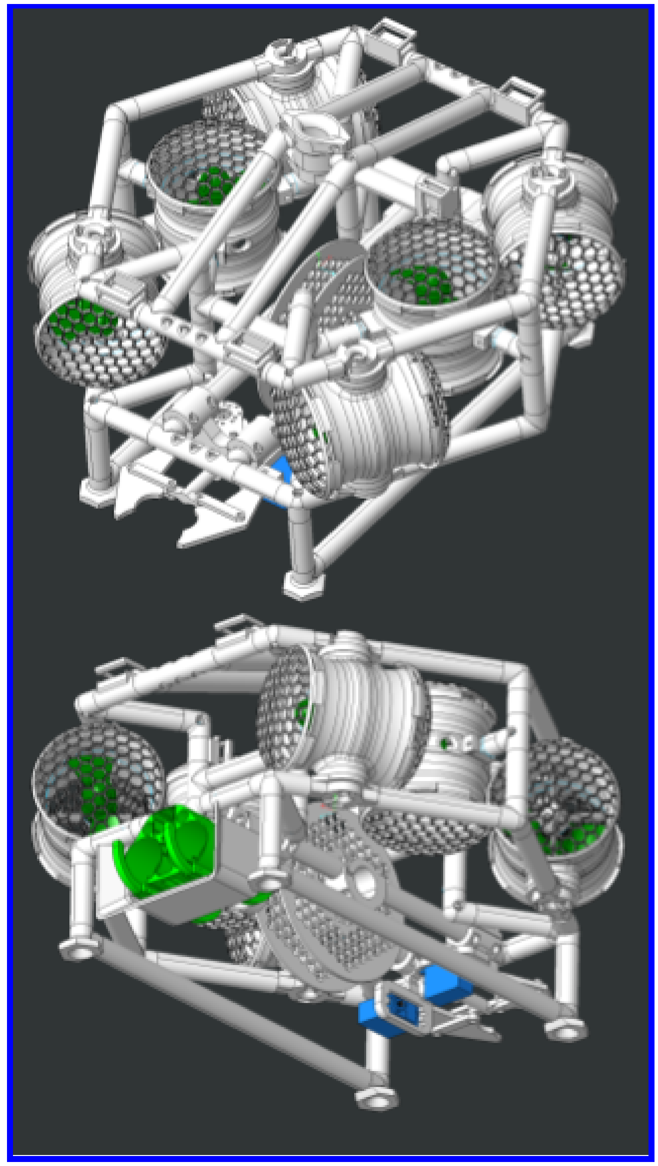


Figure 2.0 CAD Assembly of HECS' Frame

The frame design went through several iterations during its development, each increasing in complexity. The initial design was barebones and lacked any of the central components, as it was mostly a proof of concept for a horizontal frame held together by the motor shrouds. The vertical shrouds and inner hex were added next, providing a functional platform for the remaining components to be added. The shrouds are integral parts of the frame; the horizontal shrouds bind together the upper and lower halves of the frame, while the vertical frames reinforce the structural stability of the frame, making the entire frame much stronger.

Once the basic components were established, we added the central rails across the top and bottom of the frame. The bottom rail holds the mechanical claw, spool, and mini-ROV, while the upper rail holds the strain relief for the tether and capture net.

Due to HECS's unusual shape, the majority of its required parts were not available in a pre-made form which is why, with the exception of the ½" PVC piping, all of the parts are 3D-printed from PLA plastic which, as a biodegradable material, was highly suited for a vehicle with an environmental mission. We chose these materials because they are modular, easy to redesign, robust and durable, and very affordable. Any of the PVC parts can be recut and repainted with little effort, and any of the 3D-printed components may simply be reprinted; this allows us to have spare parts prepared for much of HECS should it sustain any damage. The entire HECS structure was designed by the company. None of the 3D-printed parts were designed or modeled by commercial sources or the company's consultants.

Propulsion

Motor and Propeller Design

One of our earliest goals in the design of HECS was to create our own entirely custom propulsion system that can hold its own when compared to other purchasable options, while being much more affordable. With this goal in mind, before we even began to prototype our frame, we went through a thorough process of motor testing.

We purchased three different types of brushless motors of varying specifications and waterproofed each of them. We then designed 5-8 propeller variants for each and tested each of the motor/propeller combinations using a custom test setup (Fig. 2.1, 2.2). Using this setup, we recorded the current draw and thrust as we adjusted the input voltage. After comparing and weighing the results, we found a clear winner in the waterproof 350 KV motor.

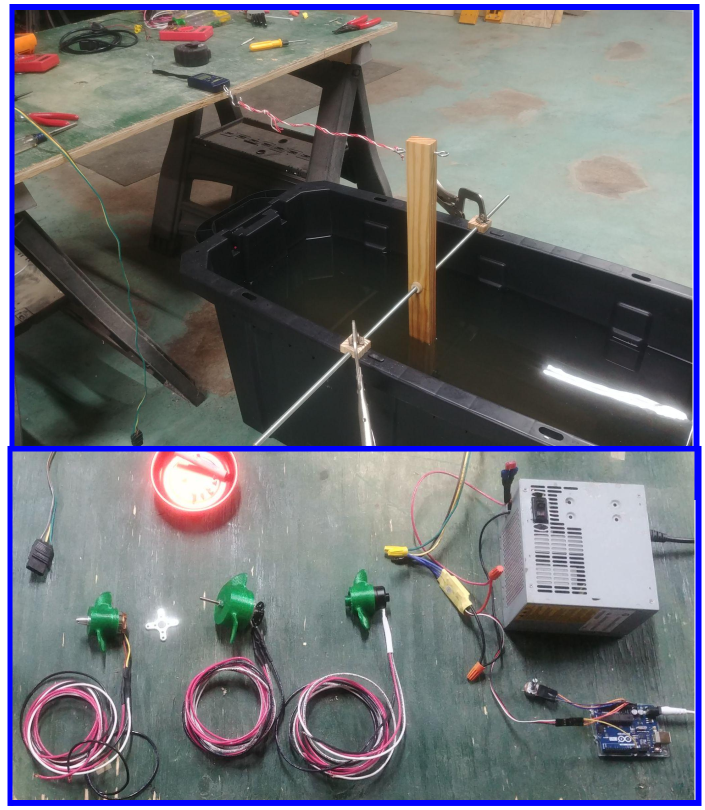


Figure 2.1 Thrust/current testing setup

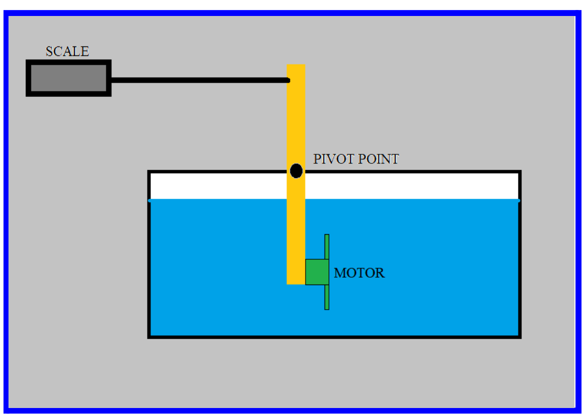


Figure 2.2 Simplified diagram of test setup

After the preliminary testing to determine which motor we would be using, we designed custom motor shrouds and further refined the propellers (ending with 25 propeller versions overall) to maximize the thrust output. Our resulting thrusters are capable of outputting ~1.5kg of thrust each, while only drawing 6A at full power. When comparing this to a commonly used pre-made alternative, the Blue Robotics T-100 Thruster, HECS' thrusters provide only 8% less thrust in the 6A range at only a quarter of the price (~$30 vs $120). In addition to saving a significant amount of money that could then be used for other parts of the design, this also allowed us to easily make two full spare thrusters in the event of a malfunction.

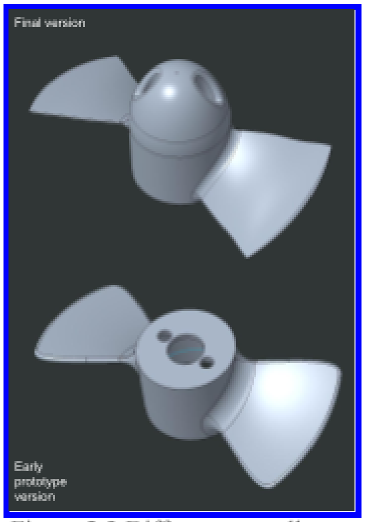


Figure 2.3 Different propeller design versions

The motor shrouds (Appendix C-3) have additional functions as well. Along with acting as mounts for the motors, their angle can be easily adjusted in three-degree increments to trim the thrust direction of HECS. This is accomplished by small teeth on the shrouds' mounting plates that slot together when assembled. When the screws are tightened down, they can not be adjusted, but if they are slightly loosened, the shrouds can be angled as needed up to 22.5 degrees in either direction.

Attachments: Manipulators

There are two different kinds of attachments on HECS: stationary hooks and a claw. The stationary hooks are 3D-printed from PLA plastic and their final designs took many iterations to achieve. The early designs were simple, merely a triangle on the end of an arm. As development continued, the designs split into different hook variations useful for different tasks, such as a very basic hook for snagging ropes/metal loops and a larger rounded hook for holding PVC. All of the designs are mounted to HECS' frame using a standard universal clamp that can be positioned anywhere and easily moved as necessary.


Figure 2.4 New, servo-driven manipulator claw

HECS' manipulator claw (Appendix C-2) is also 3D-printed and is driven by a servo. The design is an evolution of the claw we used on our previous ROV in 2019. While the original claw had many benefits, there were several key flaws in its design: firstly, it was constructed almost entirely from metal, causing it to be inconveniently heavy. More importantly though, because the primary mechanism was a lead screw driven by a motor, the claw would regularly jam open and shut, rendering it unusable without hands-on maintenance. We attempted to fix the issue by adding several different types of hardstops, using lower RPM motors, and replacing some of the metal parts with 3D-printed ones, but we were ultimately unable to find a direct solution. Instead, we took the basic design of the claw and redesigned it to work with a completely different mechanism.

Our new, servo-driven claw (Fig. 2.4) is much lighter, offers much more precision, and eliminates the jamming issue of the old claw. The only downside to the new design is the grip strength: the old lead screw design gave a strong mechanical advantage to the grabber that the servo design is unable to match. However, this was determined to be an acceptable downside as none of the tasks HECS is designed to complete require a particularly strong grip, and as such our new design is easily capable of performing all of those tasks.

The claw is useful in many applications involving carrying and manipulating objects. Its standard gripper arm design is sufficient for most applications, as it was designed with versatility in mind. However, because the claw is 3D-printed, the arms can be easily modified to complete specific tasks for minimal cost, only requiring access to a 3D-printer.

Attachments: Cameras

Our main cameras for piloting are simple car backup cameras, waterproofed by 3D-printed cases and epoxy coating. HECS will have three such cameras. The first is our primary piloting camera, looking forward from the ROV. The other two are auxiliary piloting cameras: one will be mounted on the Sediment Retrieval Tool (SRT) or micro-ROV on the back of HECS, and the other will be mounted above the front of the ROV looking straight down to assist with lining up our manipulators.

For our image recognition camera, we are instead using a higher resolution USB camera. To waterproof the image recognition camera, we repurposed an already waterproof case for an old camera. A frame was 3D-printed for the inside of the case to hold the camera in place, and a single hole was drilled and waterproofed in the back of the case for the camera wire.

Our primary driving camera will be routed to its own monitor, while our two secondary cameras will share a second monitor. Because the secondary cameras will never need to be operated simultaneously, they will be wired to a switch that allows toggling between the views. The image recognition camera is routed via USB to a laptop that then runs our image recognition software.

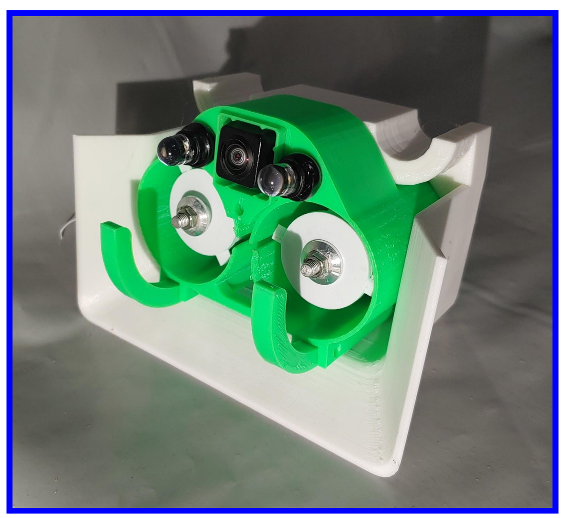
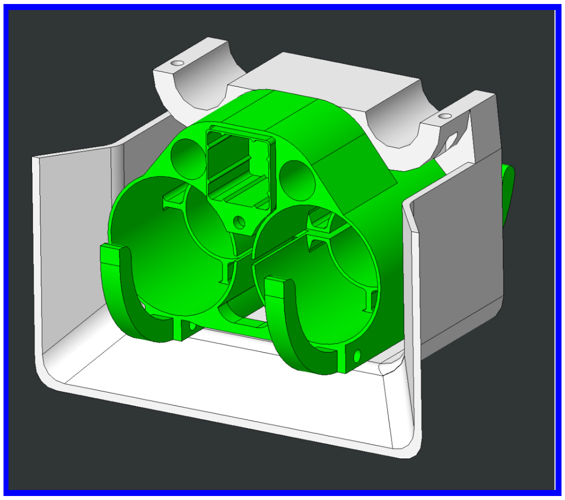


Figure 2.4 Image of the SRT

Attachments: Sediment Retrieval Tool

The Sediment Retrieval Tool, or SRT for short, is our solution for the collection of sediment samples from areas with limited access, such as within drain pipes. The body of the SRT is custom designed and fully 3D-printed, with mounts for each of its components and for its mobility skids. The SRT is equipped with a waterproofed backup camera (which additionally functions



as our rear-facing auxiliary camera), two LED lights, and two waterproofed brushless motors for propulsion. The power and control for each of these components are transmitted through a short secondary tether, mounted on a small reel in the center of HECS.

Figure 2.5 CAD model of the SRT

The mobility skids allow for smooth transit within the drain pipes and during the process of recapturing the SRT onto the ROV. The SRT, while not deployed, is stored within a 3D-printed capture box (Fig. 2.5, shown in white) situated on the back of the ROV just behind the tether reel.

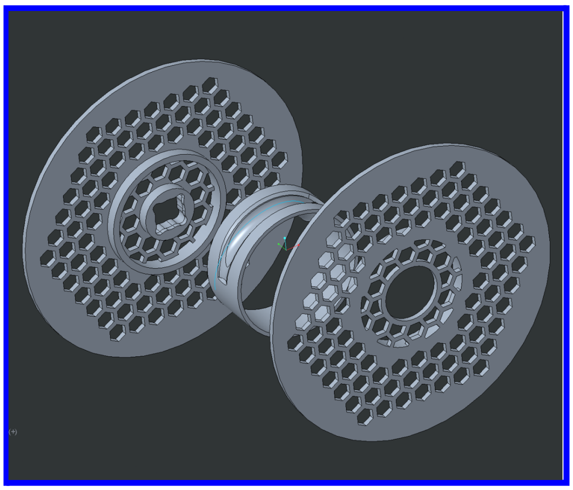


Figure 2.6 SRT Tether Reel Exploded View

The tether reel for the SRT (Fig. 2.6) is made up of three 3D-printed pieces that form a narrow spool when glued together. The small tether is wound around the reel, which is connected on one side to a brushed motor that spins the attachment when activated. It may spin in two directions; either releasing tether so the SRT may move further away or rewinding the tether around the spool to pull it closer to HECS. Located between the capture box and the tether reel is a 3D-printed fairlead to help route the tether back into the spool. Early in testing, we experienced issues with the tether slipping off of the reel and getting tangled up in the reel motor and axis; the fairlead has consistently prevented this.

The specific mechanism for taking hold of the sediment samples is deceptively simple: hook-and-loop fastener pads are attached to the front of the mobility skids. When the SRT is piloted into a drain pipe, it will run into the sediment sample, engaging the hook-and-loop fasteners on the sample. The SRT can then be reversed, retrieving the sample.

Design Philosophy

The basis for the design of nearly all of our mechanical components was the desire to have an ROV that was almost completely made from scratch. None of our components were purchased ready-to-attach, they were bought as simple motors, electronics, and servos, then modified by us to function underwater on HECS. Despite this, we have been able to make a fully functional and modular ROV for a fraction of the cost of others with similar capability. Our belief in doing so is that such an affordable ROV must be the future of environmental cleanliness and recovery: the effort must be widespread, and thus must be accessible to as many people as possible.

Electrical Review

Onshore Electronics

Figure 3.0 Inside view of the EHC

The Electronics Housing Case, or EHC (Fig. 3.0), contains the electronics of the ROV and connects to the ROV via the tether. The EHC contains the Raspberry Pi, the power and ground busbars, the voltage regulator, the pulse wave modulator, and the video input selection switch. The Raspberry Pi serves as our main control, receiving signals from the game controllers and turning them into commands for the pulse wave modulator, which then sends those commands as PWM signals to our ESCs. The voltage regulator makes sure that the power to the servos is kept at the correct voltage, since the servos need to receive a reduced 7V compared to the rest of the 12V system. The video input selection switch allows us to toggle between our two auxiliary-view cameras.

The EHC is set up with a base that holds the electronics, a plexiglass cover held up by 3D-printed stands, foam cushioning to keep the game controllers from jostling during transit, a hole in the side for the tether and a 3D-printed clamp around the hole for strain relief. The box is water-resistant to protect the electronics from splash hazards near the pool. The main power supply cable is fitted with Anderson Powerpoles to plug into the ondeck power source, and before reaching any electronics, the main power runs through a master power switch that can be used to cut all power to the ROV in case of emergency. Our video setup includes two monitors and a laptop: One monitor is used for our main piloting camera, the other is used with the video input selection switch for our auxiliary-view cameras, and the laptop is used with our image recognition camera.

Onboard Electronics

The electronics mounted directly on HECS include our ESCs, servos, motors, and cameras. The PWM signal wires that connect to the servos and ESCs are spliced into an ethernet cable that runs through the tether. All of the components are firmly secured to the frame using custom 3D-printed mounts which, in combination with cable ties, help to hold the wires to the frame where they cannot be easily damaged. Each of the backup cameras send their signal through individual RCA cables, and the image recognition camera uses an active USB cable.

We have two primary power wires run through our tether: a large, 10ga wire pair for our 12V motor power, and a smaller 18ga pair for our 7V servo power. We have four separate 22ga power wires for individual components/systems: one is for the SRT's thrusters, one is power for the

SRT’s lights and camera, one is for the SRT tether reel motor, and one is for the two piloting cameras mounted directly to HECS. For the sizing of our wires, we used an online voltage drop calculator to ensure that we would not experience issues.

Software Review

Motor and Servo Control

The thrusters of the ROV are controlled by two joysticks and two bumpers in the onshore controller. The two joysticks control the horizontal motors while the two bumpers control the vertical ones. This year we decided to use six thrusters, four horizontal motors mounted at an angle to the structure of HECS and two vertical motors. We also decided to use Electronic Speed Controllers (ESC) to control the motors.

We wrote a new program to translate the joystick and bumper positions into power values which then are sent to the ESCs as a digital output. The left joystick controls the two left motors and the right joystick controls the two right motors allowing us to “tank drive” the ROV. The two bumpers control the vertical motors at the same time. The program reads the position of the joysticks and calculates the joysticks magnitude and angle. Then it calculates the motor raw power and vector angle, and we rotate it to match the mounted angle of the thrusters. By scaling the motors’ power we fine tune the robot’s movements to make it easier to control at slow speeds.

The servos are controlled by a pilot. The signal comes from a pilot’s controller through a Python program running on the laptop. Then, much like the motors, the signal goes to the pulse wave modulator, through the ethernet cable, and to the servos.

Image Recognition

To complete the tasks involving image recognition and related software, our Director of Programming developed programs specifically to accomplish the challenges at hand. One such example of the produced software is the program to create a photomosaic of an underwater subway car.

For the subway car photomosaic generation, we decided to partially automate the process of creating an accurate, undistorted photomosaic to avoid the potentially large time sinks involved in doing the task manually. To accomplish this, we used OpenCV, a real-time optimized computer vision library capable of doing all the image processing required in real time. This real-time aspect allows users to both verify and (if needed) correct any inaccuracies in the stages of the photomosaic generation. Images from the camera feed are processed through our graphical Python script, which first “undistorts” the images to straighten out edges on the visible subway car. It then searches for possible tape colors in the resulting image by thresholding in the HSV (hue, saturation, value) color space, which we found to be much more lighting-invariant than RGB. The resulting images are binary masks, from which the subway car edges and corners are deduced. These corners are used to segment the image into visible car faces, which are organized by their side colors and lengths. Once all 6 unique faces are seen, the corners are used to warp the visible faces into rectangles which are then displayed in the resulting photomosaic, with all edge colors corresponding.

Reflections

Tether Layout

One of the major lessons we learned and had to adapt to during the development of HECS involved the configuration of the tether. In early designs, we decided to wire the tether such that our ESCs were situated onshore in the control box rather than onboard, which left the 3-wire groups between each ESC and motor running through the tether. We had several reasons for doing this like saving room onboard HECS, having fewer components that could fail being underwater, and a concern that PWM signals could not be consistently sent over 50ft as would be otherwise needed.

However, this plan was ultimately flawed for two reasons. This original configuration included 32 wires, leaving the tether thick and difficult to drag around, and it caused significant electromagnetic interference or EMI between the motor wires and the servo signals we were sending. When the motors were initialized, our servos would shudder uncontrollably and become unusable.

Our solution for this was to almost completely remake the tether to avoid running so many individual power wires. The ESCs were relocated to onboard HECS and the PWM signals were run through a shielded ethernet cable in the tether. This dropped the number of wires in the tether by nearly half, making it much more manageable and immediately eliminating the interference issues we were experiencing.

Tether Buoyancy:

Another lesson we learned as HECS evolved was an improved method of providing buoyancy to the tether in the water. Early on, we utilized a similar method of buoyancy as we did in our previous ROV: we secured small loops of polyethylene foam to the outside of the tether with cable ties at regular intervals. While mostly effective, this method had several issues; not only could the loops catch on corners and edges of the pool or objects around it, but they were also prone to coming detached from the tether entirely if the cable ties slipped off.

When we reworked our tether (as described in the previous section) we decided the buoyancy was also something we needed to improve. To that end, we measured and recorded the mass of a specific length of our new tether. With this information, we calculated a rough estimate of the overall density of the tether. We then factored in the same measurements for several thicknesses of closed-cell foam cord and compared the overall density of the tether with the foam to that of water. When we found a diameter that set the average density of the tether to less than the density of water, we knew we had found a buoyancy alternative that would run alongside our tether, within its outer loom, and would give a consistent, slightly positive buoyancy throughout the tether's entire length.

Waterproofing Technique

During early in-water testing of HECS, we encountered many issues that were unclear during dry-testing and would need to be resolved before it could be considered fully developed. One of these issues involved the waterproofing of connectors. Due to fears of ruining our electronics by severing their connectors, we initially kept all of our RCA (and similar) connectors intact, and instead waterproofed around them. This proved to be a mistake once in the water, as these connections were prone to allowing water into them despite our attempts at preventing it.

After this was determined, we committed to splicing the wires instead: every wire was cut, stripped, soldered, and secured with heat shrink tubing. This method has proven to be much more reliable, and additionally has eliminated the collection of bulky connectors around HECS' strain relief clamp.

Printing Infill Density

Early in the functional prototype testing, many of our 3D-printed components were printed with a sparse (20-30%) infill density, filling in only a small portion of the inner material of the component and leaving it in a square grid. This was done intentionally, because printing components this way not only makes them much lighter and more buoyant, but also saves a massive amount of time by making the print length much shorter.

Once we got the parts in the water, the downsides of this method became clear: the honeycomb-like interior of the parts weakened the parts significantly and made them prone to commonly breaking. Additionally, the grid left pockets of air on the interior of the part: while this did initially increase buoyancy, the exterior walls of the part are not waterproof at depth. While testing, water was able to seep into the chambers, altering the buoyancy of the ROV.

Since this was discovered, we have printed all components with a solid (100%) infill. While this does increase the weight of HECS, it makes the parts significantly more durable and eliminates any chambers for water to leak into.

Possible Improvements

Our company is committed to continuously improving our product and there are many aspects of HECS' design that can be improved in future versions. In the future we could improve the fit of 3D parts and the print quality, as some of our parts (specifically many of the PVC connectors) did not fit as cleanly as we would have liked.

We also could improve our project management by creating a Gantt chart. This would help us to estimate when certain tasks needed to be finished so that we would have our desired amount of testing and piloting practice. This would have given us more time and helped us to avoid getting uncomfortably close to submission deadlines.

Financial Review

A unique trait of Deep Ocean Robotics is that we are entirely self-financed. Our members fully fund the company with annual dues for participation and occasional voluntary donations of materials or equipment. Our original budgeted income this past year was $2800 from company dues while our original budgeted expenses was $1912, reserving the amount left for contingencies. After the season began we added two new members, bringing our overall income to $3600 as we received no donations or sponsorships. This allowed us to purchase additional equipment and parts we would not have been able to purchase otherwise. All equipment and parts purchased were bought new.

We have spent a total of $2145.68, $1037.11 of which are actual ROV expenses, spending an additional $1108.68 on equipment/unused materials. Any unused funds at the end of the season will be returned to company members.

DIRECT ROV COST

ITEM	DESCRIPTION	UNIT COST	QUANTITY	TOTAL
Onboard Electronics				
Brushless Motor, Waterproof,	Purchased	$26.29	6	$157.74
DC Gear Brushed Motor	Purchased	$6.68	4	$26.72
Brushless Electronic Speed Controllers	Purchased	$11.15	6	$66.90
Waterproof Analog Servo	Purchased	$43.55	2	$87.10
Water Resistant Backup Camera (Primary)	Purchased	$39.30	2	$78.60
Water Resistant Backup Camera (Smaller)	Purchased	$35.05	1	$35.05
USB Camera Module	Purchased	$48.86	1	$48.86
Cables/Wires				
100' 18 Gauge Cable	Purchased	$18.05	3	$54.15
25' Expandable Braided Sleeve	Purchased	$7.40	2	$14.80
50' RCA Cable	Purchased	$11.68	3	$35.04
100' 20 Gauge Cable	Purchased	$16.99	1	$16.99
50ft Shielded Ethernet Cable	Purchased	$23.36	1	$23.36
50ft Active USB Cable	Purchased	$21.24	1	$21.24
100' 22 Gauge Cable	Purchased	$15.93	1	$15.93
100ft. 18 Gauge Wire	Purchased	$21.99	1	$21.99
Onshore Electronics				
Raspberry PI 4 and Case	Donated	$80.00	1	$80.00
Video Selection Switch	Purchased	$24.43	1	$24.43
16 channel 12 bit Servo Controller	Purchased	$8.50	1	$8.50
Adjustable Voltage Regulator	Purchased	$17.95	1	$17.95
Logitech Gaming Controller	Purchased	$19.79	2	$39.58
Additional Materials				
Filament, PLA	Purchased	$20.18	4	$80.72
Filament, PETG	Purchased	$22.99	1	$22.99
Heat Shrink Tubing	Donation	$10.60	1	$10.60
#6-32 Machine Screws	Purchased	$9.31	1	$9.31
Industrial Strength Velcro	Purchased	$3.16	3	$9.48
Liquid Electrical Tape	Purchased	$7.42	1	$7.42
Amazing Goop Adhesive	Purchased	$7.40	1	$7.40
PVC Pipes for ROV	Purchased	$14.26	1	$14.26
			Full Price:	$1,037.11

Safety Review

Waterproofing

During our first year in MATE we used heat-shrink tubes and an adhesive sealant called Amazing Goop to waterproof any onboard connections. With the HECS, the company used a different brand of heat-shrink that has a built in heat-activated adhesive that both strengthens wire connections and seals the ends of the heat-shrink tubes. This was a monumental discovery allowing us to make wire connections more easily, securely, and quickly.

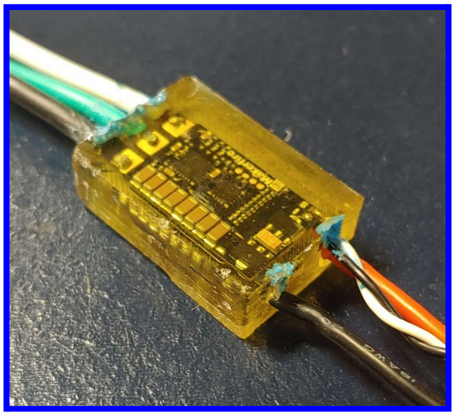


Figure 4.0 Example of waterproofing; ESC encased in epoxy

Servo waterproofing was an experimental idea that we had to run multiple tests on. The servos we purchased were initially labelled as waterproof, but not at depth. So, to make them waterproof enough for performance at depth, our first idea was to fill the servos with dielectric grease, to prevent the electronics inside from being damaged by any moisture that leaked in. When we tested this plan, the dielectric grease jammed up the gears inside of the servo causing the servo to be damaged during our overnight test. So, as a second plan, we sealed the outside of the servo with liquid electrical tape, and this successfully kept water out of the servo.

For many of our electronics that would be in the water, such as our main driving cameras and ESCs, we used a consistent method of waterproofing involving epoxy (Fig. 4.0). A case for each component was designed and 3D-printed, then the case was filled with an epoxy resin and allowed to cure. This secured the components in solid blocks of epoxy, protecting them both from the water and from physical harm. For some of these components, like the ESC shown in Figure 4.0, the cases were printed extremely thin and ripped free from the cured epoxy leaving a free-standing block of epoxy. As verification for the parts we waterproofed, we utilized several methods of testing the effectiveness of the waterproofing: these methods included using a 15ft water column made from PVC to accurately place parts under 15ft of pressure and using an old pressure cooker filled with water to simulate depth pressure. We also tested our brushless motors using the method described in the MATE MTB-001 Document regarding the waterproofing of brushless motors and found them to be thoroughly waterproof.

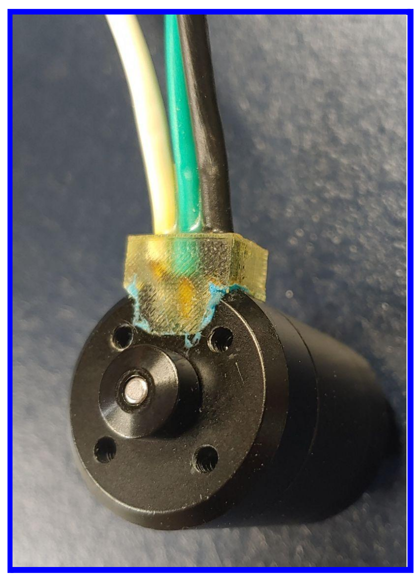


Figure 4.1 Waterproofing example: Brushless motor leads in epoxy

Wire Management

With our additional motors, manipulators, and cameras, we knew we would have a substantial tether, so wire management was a big concern. The first step we took was to add a loom to the tether. This would keep all of the wires going down to the HECS from getting tangled, getting into the props, or being grabbed by manipulators. For tether buoyancy, we strung closed-cell foam cording through the tether along with the wires. This provided streamlined and consistent buoyancy along the tether, minimizing the chance of the tether getting snagged on any corners or edges.

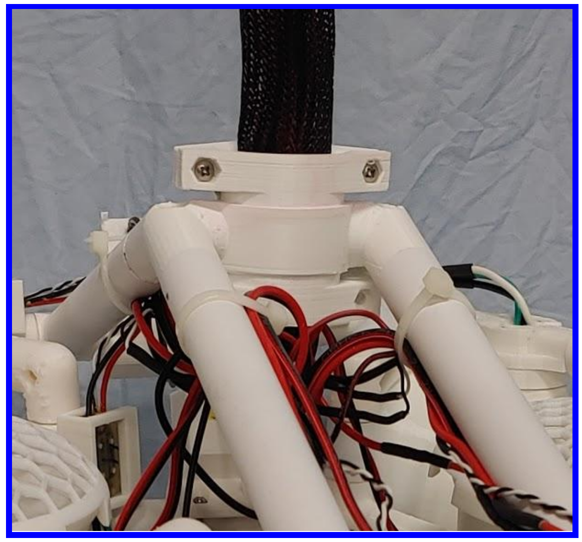


Figure 4.2 HECS' Tether Clamp

Our ondeck electronics collection, referred to collectively as the EHC (Electronics Housing Case), had several issues when it came to wire management. The PWM controller was free floating, so there was a case modeled and printed for it. Most of the electronics came with their own cases to be anchored to the base, and the rest had mounts 3D-printed for them. Even though all of our wiring was done to prevent any exposed power wires, we covered the whole electronics board with a plexiglass cover as an extra precaution and to provide a mounting plate for any control switches that could not be more easily held by hand.

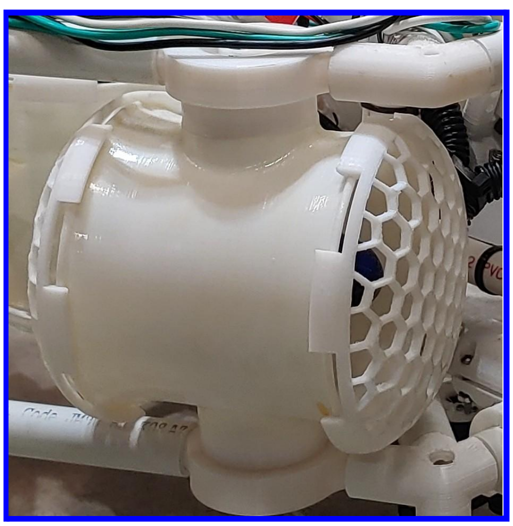


Figure 4.3 HECS' Shroud Cap

Thruster Safety

The motors and accompanying shrouds were designed with safety in mind. The motors were waterproofed using epoxy: the brushless motors we used came mostly waterproofed as purchased, as the stator and main electronics were already coated, but the wire leads were still exposed. We addressed this by coating the exposed area around the wire leads in a small block of epoxy.

To prevent the propeller blades from being exposed, we designed domed casings that snap onto the ends of the shrouds, preventing any objects (like fingers) from being caught in the propellers. The hexagonal grid has spaces of 11.5mm, which satisfies the requirement of < 12.5mm.

Individual Safety

During testing, operation, and construction of the ROV there are many steps that can be dangerous, but we have taken steps to reduce or eliminate these risks. All of these risks and the steps we have taken to reduce them have been summarized in an easy to reference Job Safety Analysis (JSA).

The major risks while testing and operating are tripping and/or falling into the pool, hand or foot injury, shock hazard, neck injury, and hair damage. To reduce tripping, we make sure all cords or wires are visible and are never dragged on the ground if they are being carried. In case of an accident involving someone falling into the pool, no one ever goes to the pool alone and there are rescue implements accessible. To reduce hand or foot injury we have two or more people carry the ROV, we round out all sharp edges, and we have encased our motors/propellers with shrouds. To eliminate shock hazards, we ensured that there is no exposed wiring anywhere on the ROV. Onshore electronics are covered by plexiglass, and all onboard electronics and wire connections are securely waterproofed. To keep long hair from getting wrapped in motors or stepped on, causing neck strain or injury, we make sure it is always tied back.

During construction and maintenance, risks include tripping, hand or foot injury, eye damage or fume inhalation, neck injury and/or hair damage, shock hazards, and electronics damage. To minimize tripping hazards, we keep cords out of walking space and pick up any fallen or dropped objects when we see them. To reduce hand or foot injury we make sure everyone wears gloves when handling sharp or hot objects, and when using glue. We also stress that everyone wears close-toed shoes to every meeting. To lessen the risk of eye damage we ensure that everyone wears safety glasses if within the reach of debris. To protect against fume inhalation, we use paint outside. To prevent electric shock, we make sure that everyone is clear before we turn the power on, we also turn the power off if anyone needs to work on the electronics. To protect against damage to the electronics we installed a fuse, within six inches of the power supply, in case of a fault in the circuit.

For Covid-19 safety we made sure that face-shields were available for all members for in-person meetings. At the end of each meeting these face-shields were disinfected with isopropyl alcohol. Each face-shield belonged to only one individual so there were no health concerns regarding the sharing of the shields. At the entrance to the work area we have a sanitizing station with hand sanitizer and an alcohol spray bottle for cleaning contaminated surfaces. There are two sinks in the work area giving access to soap and water for better sanitation.

Project Management Review

DOR has two main tools in our project management. Our first tool is a large white board in the work area. We have written down tasks, research, items to be purchased, and useful notes. We organized our tasks by their urgency, for example putting tasks such as rewiring the tether above building props for testing. We used the white board to keep track of dates, so that we would be prepared before deadlines. We wrote down subjects that needed to be researched such as how far a USB cable can go and how we can extend the signal. We used the white board for keeping track of what we needed to purchase such as a new camera or more 22ga wire. We kept notes on the board as to how specific tasks should be done or listing the necessary cables for the tether. The white board is our most integral project management tool. Our second tool is an instant messaging platform called Discord. We use Discord for distributing files, scheduling meetings, to make announcements, send out updates, and even have virtual meetings. Discord allows the company to have different channels where certain topics can be discussed and easily reviewed without having to comb through emails. It gives us a more organized and centralized location to manage company information. Using Discord's voice/video chat functions we have had key management meetings, from deciding how to organize our technical report to deciding if DOR would continue to the world championship. Using these two devices DOR has greatly improved over our project management from last season.

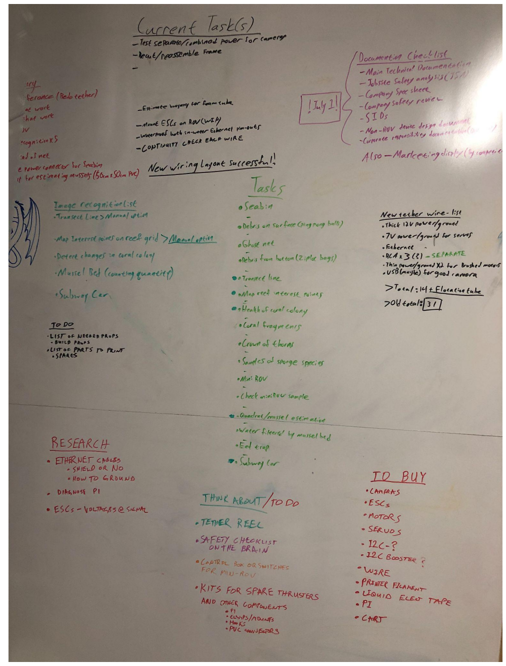


Figure 5.0 The White Board

Figure 5.1 Discord Logo
(credit: image from discord.com)

Appendices

A. Acknowledgements
B. References
C. Technical Diagrams/Drawings

A: **Acknowledgements**

Deep Ocean Robotics would like to acknowledge and thank its members and consultants for supporting the company with their time and energy, and families of those involved for providing moral support, assistance in transportation, and financial support. Deep Ocean Robotics would also like to more specifically thank the Blaine family for providing the DOR a place to meet and allowing us the use of their machine shop as our work area. DOR would like to thank UTSI who provided DOR with funds for company uniforms. DOR would like to acknowledge the First Tech Challenge (FTC) where we increased our knowledge of project management and mechanics, and would like to thank the Arconic Foundation, Boeing, and the Texas Workforce Commission for financial aid with our FTC experience.

B: References

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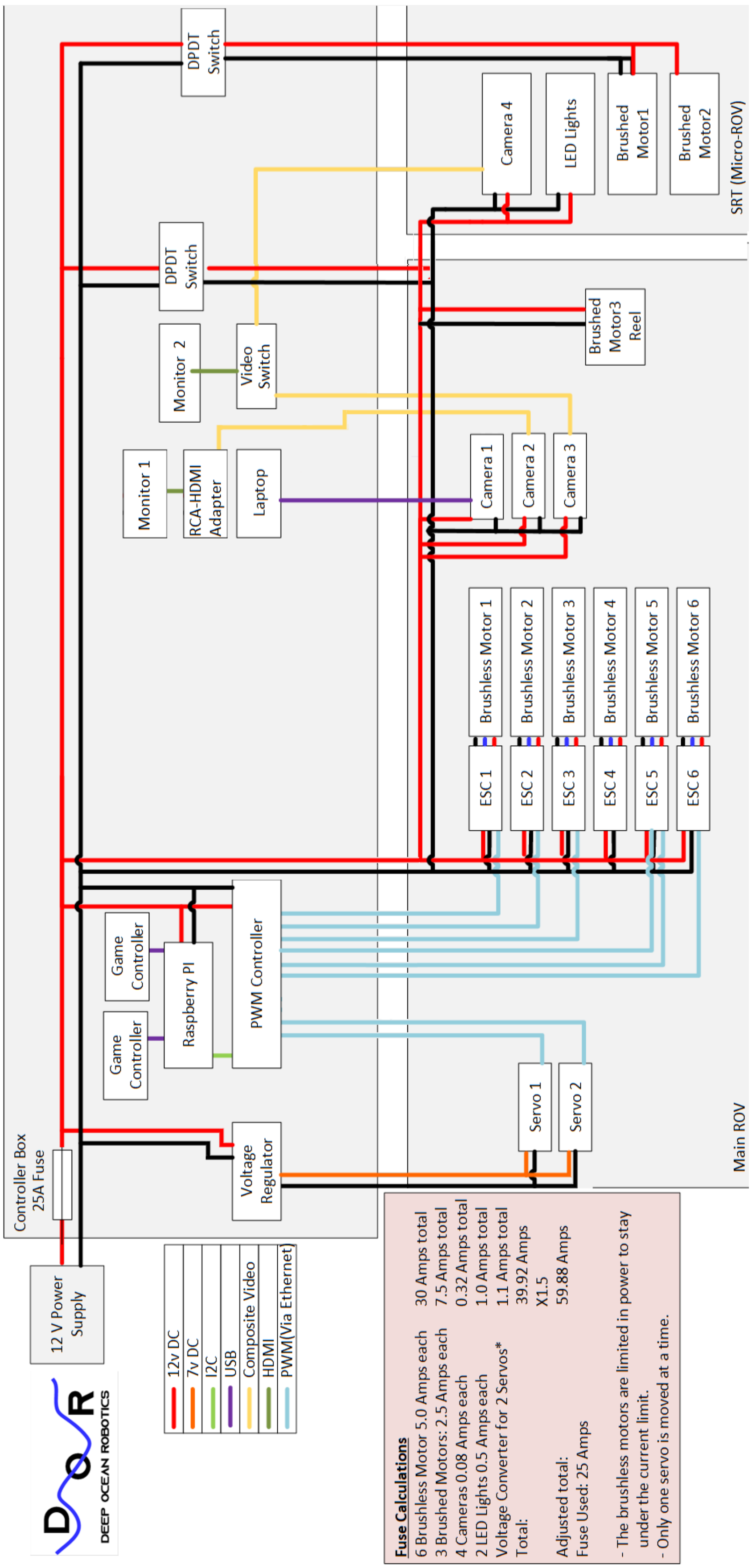
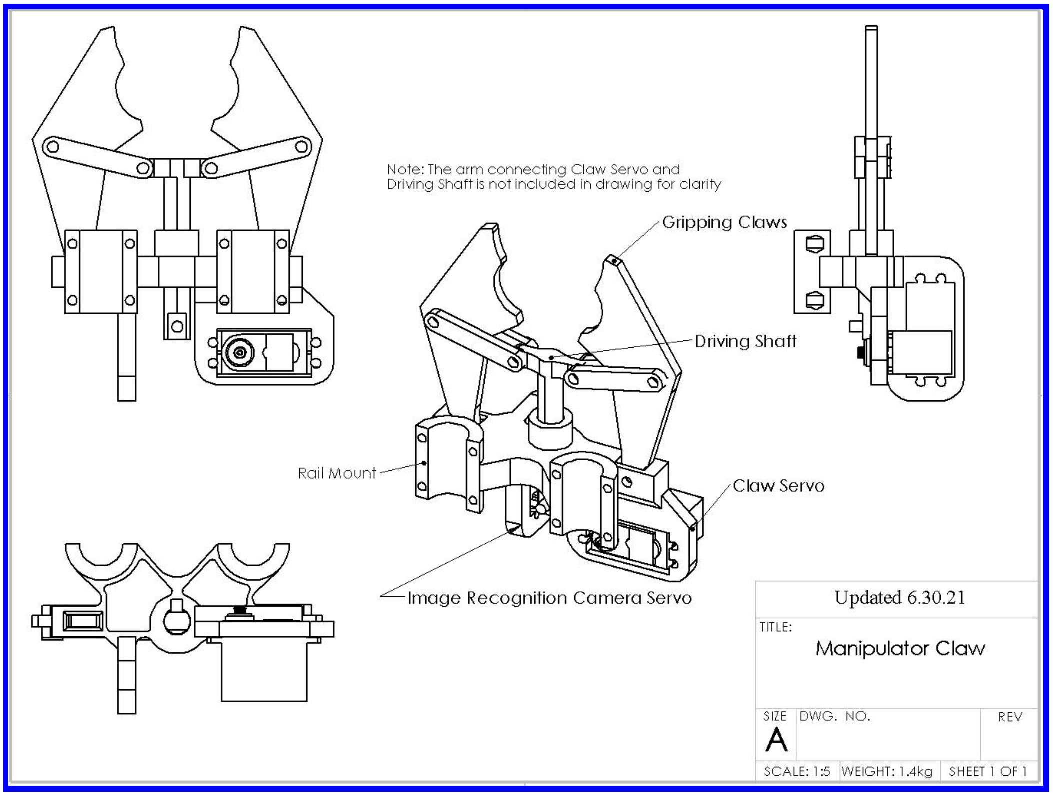
C: Technical Diagrams/Drawings --- 1: SID



C-2: Manipulator Claw Drawing



C-3: Horizontal Motor Shroud Drawing