UNDERWATER ROBOTICS TEAM

MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

ROLLA, MISSOURI, USA

2021-2022 MEMBERS

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Introduction

Abstract

The *SS&T Missouri* is the latest ROV created by the Missouri S&T Underwater Robotics Team, and the first to make it to MATE ROV's annual competition. *Missouri* is the culmination of years of hard work, dedication, and knowledge from each of our members, and the team is extremely proud of its completion.

The *SS&T Missouri* is designed to be an adaptive ROV that can tackle any challenges. *Missouri* has a dynamic manipulator that consists of a single linear actuator in a watertight enclosure, allowing for multiple attachments to be used. *Missouri's* custom-made dynamic enclosure endcap allows the shaft of the linear actuator to move freely while remaining watertight due to the dual dynamic O-rings and a pair of static O-rings. The use of the linear actuator manipulator allows for almost all the tasks to be completed without the use of pneumatics or hydraulics, and simultaneously simplifies the mechanical and electrical systems in *Missouri*. With the current challenges that face our world, an ROV must be simple to adapt, deploy, maintain, operate, and teach to others. *Missouri* allows for those principles to be put into practice to combat global hunger and climate change.

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Design Rationale

The *SS&T Missouri* was designed to be a universal ROV. The *Missouri's* frame is sized to allow the facilitation of new manipulators, sensors, cameras, ballast system, and possibly a small ROV. The *Missouri's* dual Raspberry Pis allow for both computing for autonomous and general operations. The electrical system is simple yet robust, allowing for ease of maintenance and learning. With eight T200 thrusters, the *Missouri* is able to glide through the water with ease. Over all, the *Missouri* is simple enough to operate and maintain, yet adaptive enough to conquer any challenges she may face.

Evolution

The concept to keep *Missouri* adaptive was the core of the challenge. The frame was able to keep the size and shape but the main enclosure was lowered into the frame to reduce drag after fluid analysis was conducted on the design. The manipulator's shape changed over the course of the build season. This was due to constant testing with the props to ensure proper contact with them.

The electrical system on the *Missouri* started with a printed circuit board layout but due to inexperienced members, the main electrical system was simplified to deal with these issues. This allowed for additional computing to be used in the form of two Raspberry Pi's with the addition of a networking switch. The discovery of ArduSub and the donation of PixHawks completed the on board electrical and computing system. The addition of the electrical system meant we had to design a new mounting system for inside the enclosure. Even with all of the challenges that the team faced, the *Missouri* was completed in time.

Mechanical

The Mechanical Division handles the design and construction of the ROV frame. Areas of expertise among members of this division include but are not limited to computer aided design, producing components using additive or subtractive machining, and assembly. The process of designing the ROV starts with the basic framework and progresses to the implementation of smaller subassemblies.

Organization

The mechanical division is led by the mechanical division lead who delegates and oversees all projects as well as organizes weekly meetings. The mechanical division meets once a week in the SDELC (Student Design and Experiential Learning Center), our collaborative workspace at Missouri S&T. At first, semester meetings were held on Wednesday at 5:30pm, but this changes every semester as class schedules change drastically for each member.

Projects and responsibilities are posted on the division Trello board which can be accessed and updated by all members. During each meeting, the division head will ask for progress updates from each member and offer assistance or suggestions as needed. The division head also communicates deadlines and other important information to members during this time. Afterwards, any division-wide projects are worked on by all members.

All CAD design and drawings are done in SOLIDWORKS because it is provided for free by Missouri S&T. Any documents or files relevant to projects are uploaded to the team's shared Google Drive.

Frame

Missouri's frame was completely redesigned from previous ROV iterations for the 2021-2022 competitive year. The primary goal of this redesign was to allocate more space to onboard electronics and control systems as well as align drag and thrust vectors so that there is very little deviation when translating through water without relying on corrections from gyroscopic sensors.

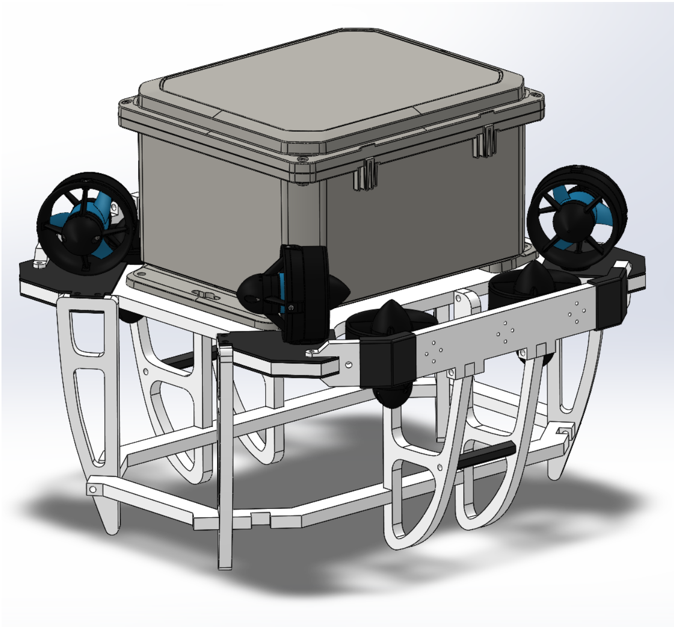


Figure 1: Initial Frame Redesign

The new frame design was initially overly complex and utilized multiple materials, which was undesirable. It also lacked rigidity and required an unnecessarily large quantity of fasteners. From this initial design, it was determined that using a singular material and minimizing the quantity of fasteners required was a main priority for both ease of repair and for improving strength. This design also appeared messy and lacked presentability as well as free space. However, the thruster layout from this initial design was kept in the final design because of the agility and fine control that it allowed. Overall, we appreciated the core idea but saw much room for improvement. The design was cleaned up and separated into three distinct platforms to ensure enough space was available for cameras, manipulators, ballasts, etc.

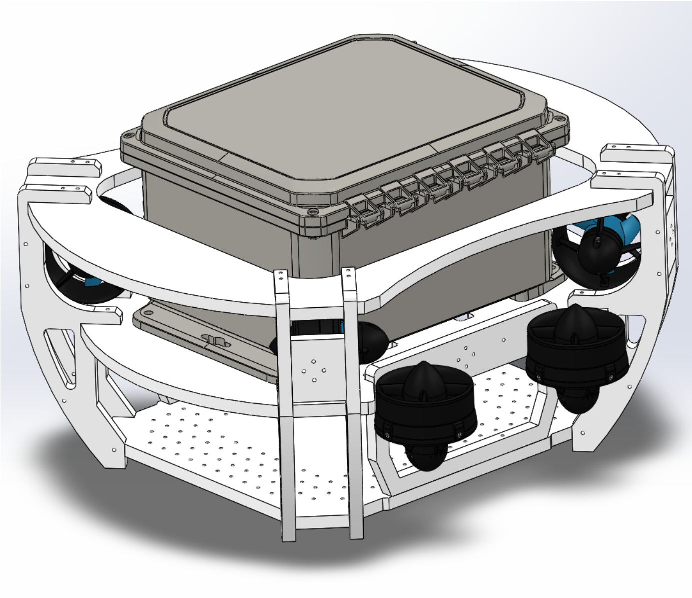


Figure 2: Final Missouri Frame

The frame is made entirely of 0.5in polypropylene sheet. Polypropylene was chosen because it has roughly 90% of the density of water, making it slightly positively buoyant. Based on success with polypropylene as the material for previous ROV versions, it was the strongest candidate. Every component was made to be of identical thickness to make manufacturing as simple as possible because it allowed for the entire frame to be waterjetted, leaving only a few holes needing to be drilled after assembly.

Knowing some of these holes would be tricky to drill precisely, custom 3D printed alignment tools were used to ensure precision and accuracy. Almost every joint between separate components is an interference fit, meaning that nearly the entire frame can be assembled without need of any fasteners save for a handful of crucial locations. However, all components are fastened with bolts and nylock nuts to withstand more significant forces and improve durability. The size and shape of the main enclosure defined many aspects of Missouri's frame.

Ensuring that there was ample space to manage cables and and access the main enclosure was top priority for safety and efficiency. The enclosure was placed such that the hinged lid sat just above the top of the frame so it could open without any obstructions. The enclosure's large rectangular profile also generates significant drag forces when moving through the water, so the main thrusters were placed such that the center of drag resistance for the entire frame and the center of thrust were approximately identical so there was minimal undesirable pitch rotation when translating. The entire design is symmetrical, about the yz-plane, except for manipulators, so undesirable yaw rotation is not a concern.

Thrusters and Guards

In total there are 8 T200 Blue Robotics Thrusters on *Missouri*. The upper four are the main thrusters which control translation along the x and y axes as well as yaw. These thrusters are placed at 50 degree angles such that slightly more thrust can be delivered in the direction of forward translation. The lower four thrusters are responsible for ascending and descending along the z-axis and pitch and roll. T200 Thrusters were favored over T100 despite the added cost due to their increased thrust output as well as durability and lifespan. T200 thrusters are more equipped for longer periods of continuous output so there is no need to limit the capability of *Missouri* to protect the thrusters.

Guards for the thrusters were designed and 3D printed by a member of the mechanical division, with the purpose in mind of preventing foreign objects from entering and damaging the purchased thrusters. The most challenging aspect of this creation was addressing the space constraints of the ROV. The space allotted by the *SS&T Missouri's* frame was limited, and creating a design that accommodated both the thrusters and guards was demanding. The design and printing of the thruster guards took an estimated 8 hours.

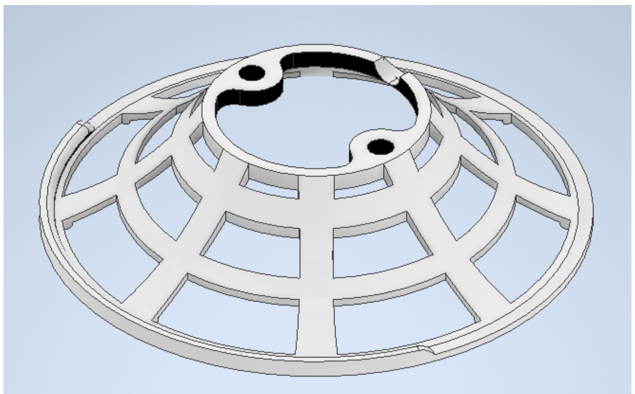


Figure 3: Finalized Thruster Guard Design.

Float

The first step in designing the float was identifying criteria and constraints and doing research on existing products. The screenshot provided below provides an example of a GO-BGC float used by MBARI. Using the MBARI float as inspiration, the following concept sketches and design ideas were created.

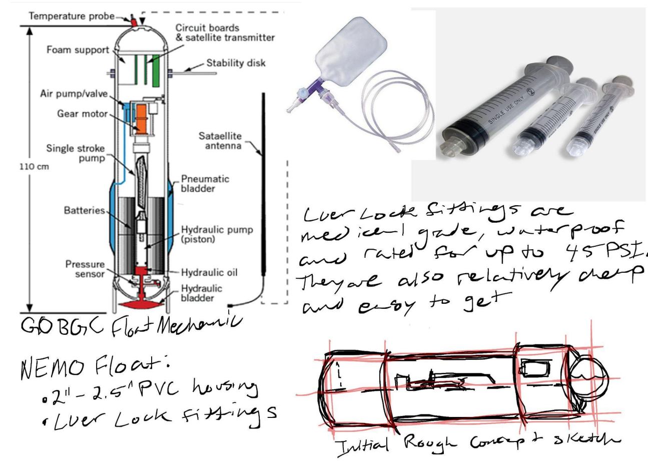


Figure 4: Initial concept sketch and brainstorm of components for the float

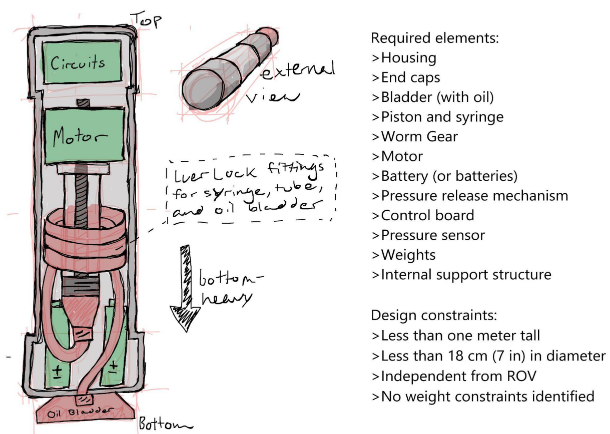


Figure 5: Refined concept sketch and identification of required elements and constraints

One of the main problems encountered while working on this problem was time management. Although everyone assigned to this project was very excited to explore this aspect of the competition, the most significant obstacles in the construction of the float were constant scheduling conflicts. Additionally, not enough work was done initially to define the criteria and constraints for the design, which led to constant redesigns of the float and a lack of tangible progress in construction. As of right now, the float is still in the very early stages of layout testing, and some components have not yet been acquired.

Figure 6: Layout testing for the float, with the syringe, circuit board, and motors present

Both of the team members involved in the float project intend to commit a total of approximately 15 hours towards the floater project, and produce a working prototype by the time of the competition. The goal is to have the floater complete at least one full descent and ascent cycle for a total of 25 of the 35 possible points.

Static Manipulator

The static manipulator is one of two manipulators being used on the SS&T Missouri. It was created for lifting and moving objects without relying on a linear actuator to work, as opposed to the dynamic manipulator, address next. The team struggled to create a design that could maneuver items without tangling, damaging, or dropping them during the ROV's ascent to the surface. The static manipulator took two hours to design.

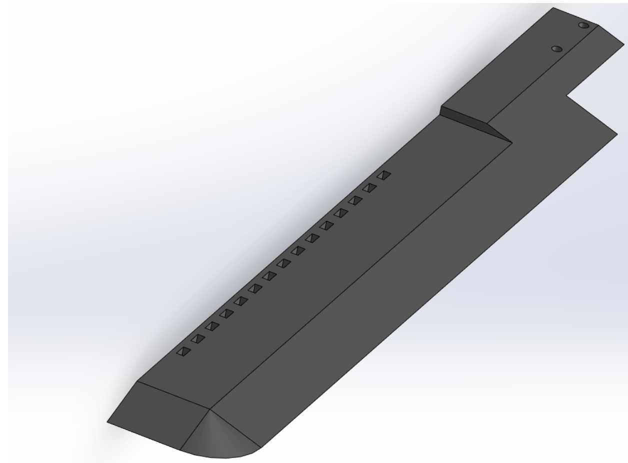


Figure 7: Static Manipulator, Created May 20, 2022

Dynamic Manipulator

The original concept for the ROV used two manipulators; one dynamic and powered by a linear actuator, and the other a simple static hook. The intent was for the static to be used for tasks that required less precision, while the dynamic would handle objects that demanded more careful movement and secure handling Throughout multiple iterations of the dynamic manipulator's design, the concept that remained constant was a pin-in-slot mechanism for turning the translational motion of a linear actuator into rotational motion of the claws, as shown below.

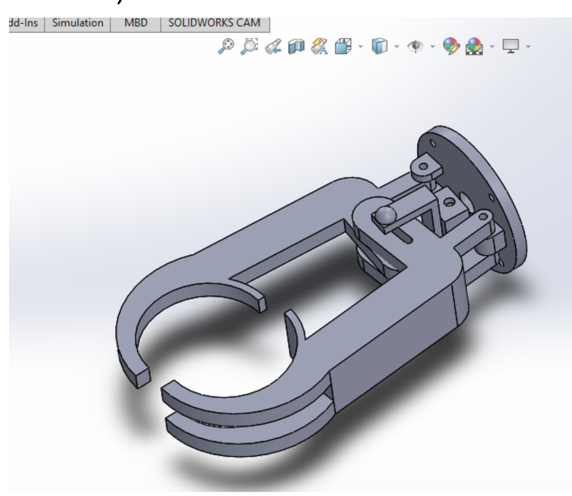


Figure 8: Design 2, Created April 17, 2022

The first few designs had a single/double claw system with a bracket connecting them to the linear actuator. It was found through testing that the actuator struggled to overcome the friction generated in this system, and this was rectified in the fourth design by angling the slots to reduce the amount of surface area overlap, as well as increasing the tolerances between the parts. The single and double claws were also reduced in thickness and extended in length. This increased reach and made it easier to grab and hold onto objects. Since objects were found to get tangled or caught up in the claws of the previous design, this revision also aided in releasing the manipulator's cargo.

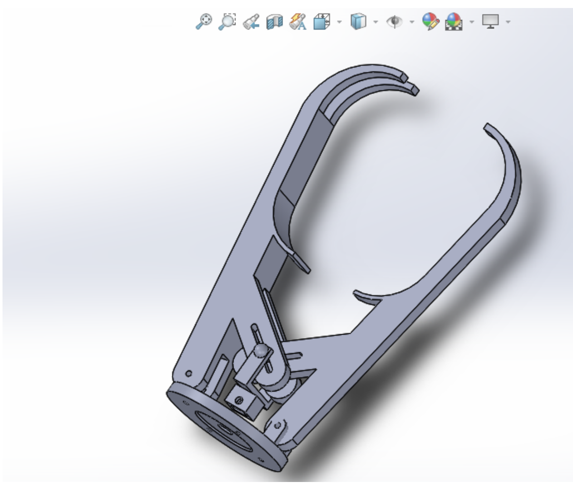


Figure 9: Design 4, Created May 12, 2022

Further testing revealed difficulties in acquiring items that lay on the bottom surface of the site which led to the most recent design, featuring a hybrid of the previous claw system and the original static manipulator. By using a stationary bar with inclined edges in place of the double claw, the manipulator can now easily slide under the desired object on the floor, and keep it in place with the dynamic single claw.

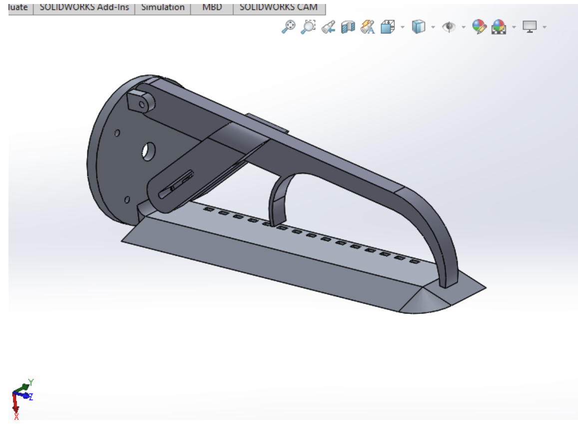


Figure 10: Design 5, Created May 19, 2022

The single claw was also modified by offsetting the slot and creating a duplicate on the other side of the claw. This eliminated the need for the bracket, leading to a simpler and more efficient mechanism. To reduce the risk of dropping the item, the claw was lined with an adhesive rubber strip, and a second static bar was installed parallel to the system. A section of fishing net runs between the bars acting as a safety net during transportation.

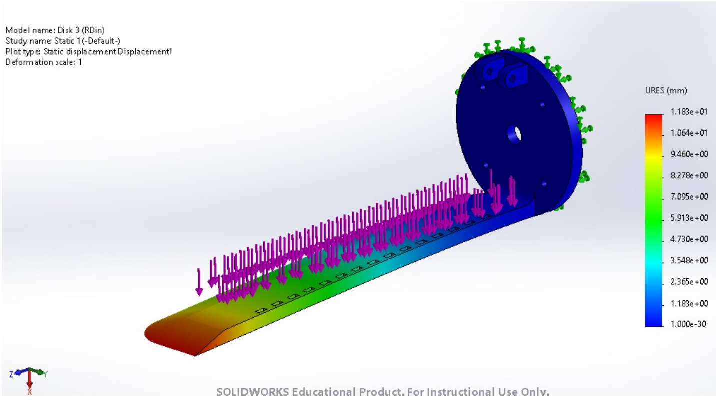
Dynamic Manipulator FEA

In the final redesign of the manipulator system, the static and dynamic concepts were combined into a hybrid mechanism. Instead of the four parts of the other dynamic designs, this version has only two. One is the same single claw from the previous design, and the other is a static bar with inclined edges and holes for attaching a fishing net, which was designed specifically for picking the fish off the bottom of the pool. This bar protrudes from the bottom of the disk which used to be the central connection for the double/single claw system. Due to the weight of the fish prop and the size of the bar itself, it was decided that a Finite Element Analysis should be run on the part to determine which of the two main materials at the teams disposal should be used to manufacture it. Two static tests were run; one with ABS 3D printing plastic, and the other with Aluminum 6061 Alloy. Fixed geometry and a load of 3lbs were used. The results of each test are shown below.

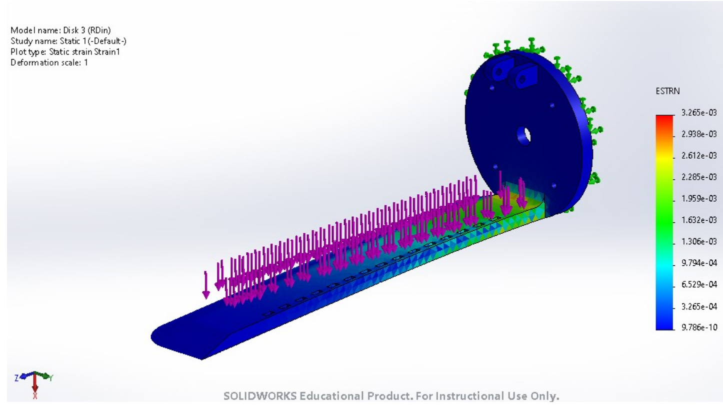
Static 1 (ABS):

The actual material the part would be made out of is PLA, however this was not an option in SolidWorks' materials list, so it was decided that ABS was similar enough to give a good approximation.

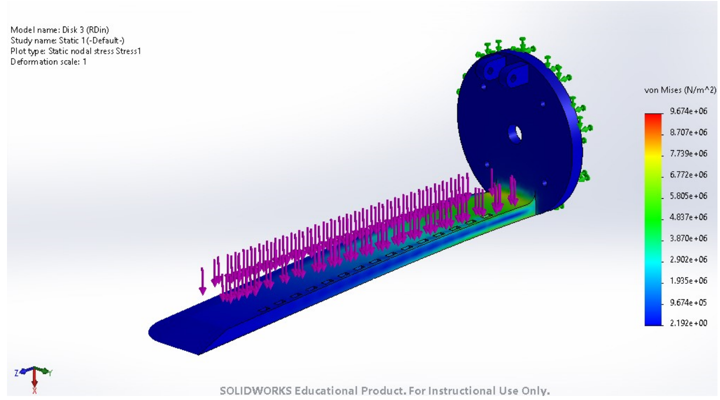
Displacement



Strain



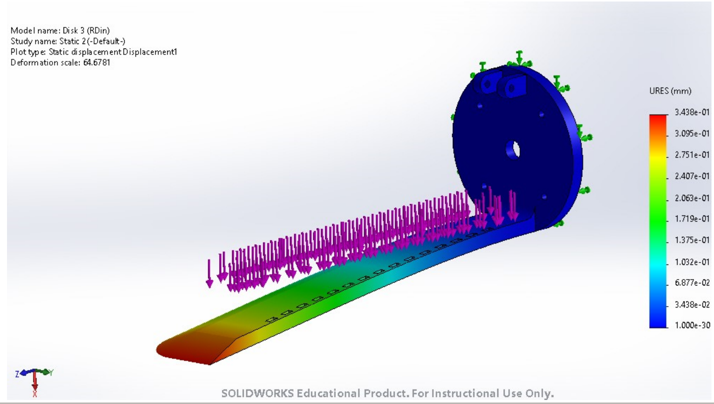
Stress



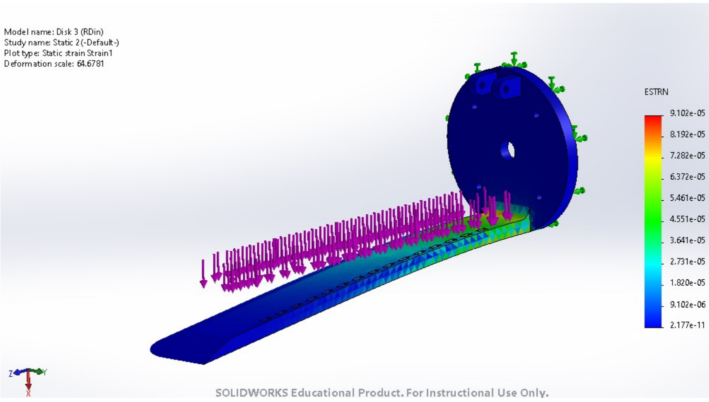
Figures 11-13: Stress tests for static manipulator type 1

Static 2 (Aluminum Alloy 6061):

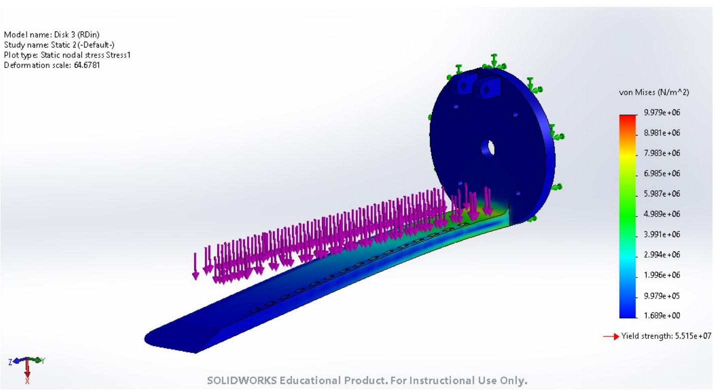
Displacement



Strain



Stress



Figures 14-16: Stress tests for static manipulator type 2

As shown, ABS had a greater tip displacement than the Aluminum 6061 Alloy (1.183mm vs 0.3438mm) as well as more strain at the joint between the bar and the disk (.002612ε vs .00007282ε). However, these tests were done with the understanding that the total force of the fish would be less underwater, and that the full resultant force of the fish would not necessarily be directly or solely on this beam, since there would be a second bar with a net spanning the two. In addition, using the aluminum alloy would require a CNC machine to manufacture it, and having that much added weight on the end of the linear actuator housing was considered undesirable. Due to the outside factors, which includes time constraints such as the need to build and test this latest design, even with the results of the FEA, it was decided that the part would be 3D printed using PLA plastic since it would be easier and quicker to create.

Manipulator Enclosure

The manipulator enclosure houses a single 12V Actuonix L12-I Linear Actuator with a 100:1 ratio and 100mm stroke length and uses a single 4.5mm Low Compression Wetlink Penetrator from Blue Robotics. The housing itself is made of a 9in long section of 1in schedule 40 PVC pipe, a slip-to-thread coupler and a flat-faced threaded end cap. The linear actuator is held in place by a circular alignment guide that friction-fits over its housing and against the inner wall of the PVC pipe and a wire carriage that has a flange which is compressed by the pipe and end cap within the coupler.

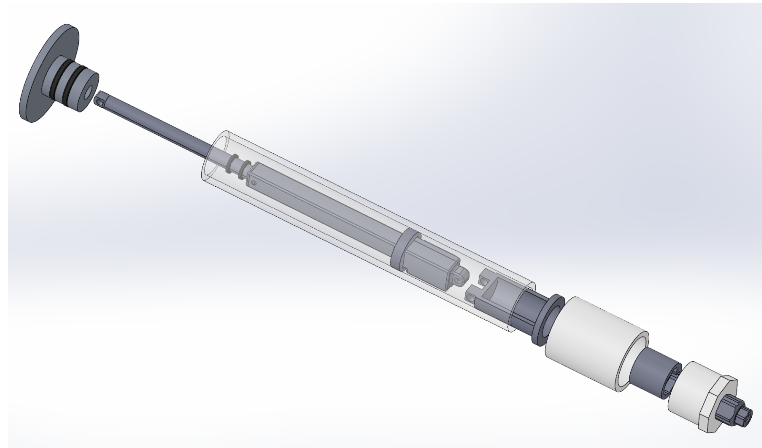


Figure 17: Exploded Manipulator Enclosure

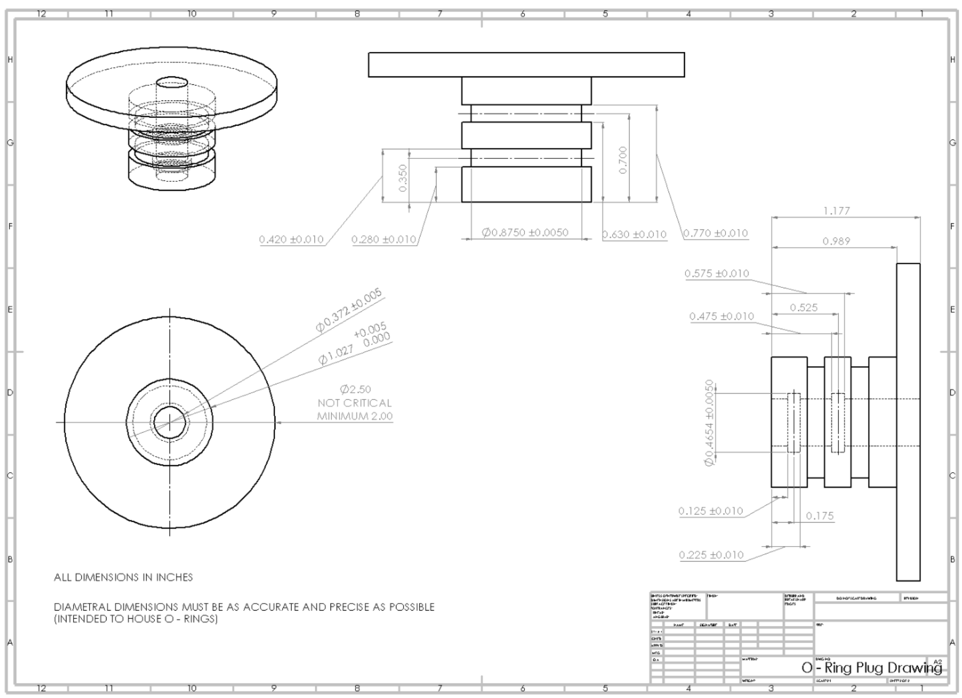


Figure 18: O-ring drawing

To ensure the wetlink penetrator can be removed if necessary, a 3D printed part was epoxied to the inside of the end cap to prevent the nut from rotating. All PVC sections were fused together using PVC cement. The aluminum plug on the opposite end of the enclosure has two sets of two grooves that hold o-rings. The inner grooves hold 1.78mm x 8.78mm Nitrile 70A durometer o-rings. This creates a dynamic rod seal around the shaft of the linear actuator which has an OD of 8.95mm. The outer grooves hold 2.5mm x 21.5mm Nitrile 70A durometer o-rings. This creates a static piston seal against the inner wall of the PVC pipe. The static seal is designed to stretch and squeeze the o-rings slightly more to increase friction and prevent slipping, as opposed to the dynamic seal where slipping is desirable. To assist the dynamic seal, silicon grease was used to further reduce friction.

Apple Rubber's online gland design tools and tables were utilized to assist in finding suitable o-rings for each gland.

Electrical

The Electrical Division focused on creating and implementing the physical electrical systems required for operating the *SS&T Missouri.*

Organization

This division follows the same structure as the mechanical division. The electrical lead is responsible for overseeing the operations of the division members, as well as ensuring completed work is on-time and operational.

The Electrical Division meetings were held at 5PM on Sundays for most of the '22 build season, then switched to an as-needed basis towards the end of the year, when the ROV was in an almost-complete state. At each meeting, delegated projects were discussed, collaboration between members was facilitated, and physical work was completed in the electrical lab.

Tether

The tether is made of two chords purchased from Blue Robotics. There were the High Power Cable and Fathom ROV Tether. These were selected since the WetLink Penteters that were tested early that year worked and offered ease of testing. The previous tether was out of date and needed to be replaced. This was a great upgrade compared to the one from years past.

Bottom Plate

The power is initiated on the surface and sent through the tether to the bottom plate where it is then converted through various voltage regulators. The bottom plate is the home of the higher voltage regulators/converters that attach to rails that then go on to power the rest of the circuitry. The components here are water resistant in the case that water gets into the enclosure.

The bottom plate features:

- 48V Power Rails: Connects the 48V power from the tether to the inputs of the 24V converter and the 12V converter.
- 24V Converter (two): Has inputs of the 48V and ~30A from 48V power rails then converts those inputs into 24V and maximum 30A outputs onto the 24V power rails to be used by the ESCs (Top Plate Side A).
- 24V Power Rails (two): Connects the 24V converter output (24V and maximum 30A) to the ESC power wires.
- 12V Converter: Has inputs of the 48V and ~30A from 48V power rails and converts those inputs into 12V to be used by the linear actuator (Top Plate Side B), as well as the 5V converters (Top Plate Side B).

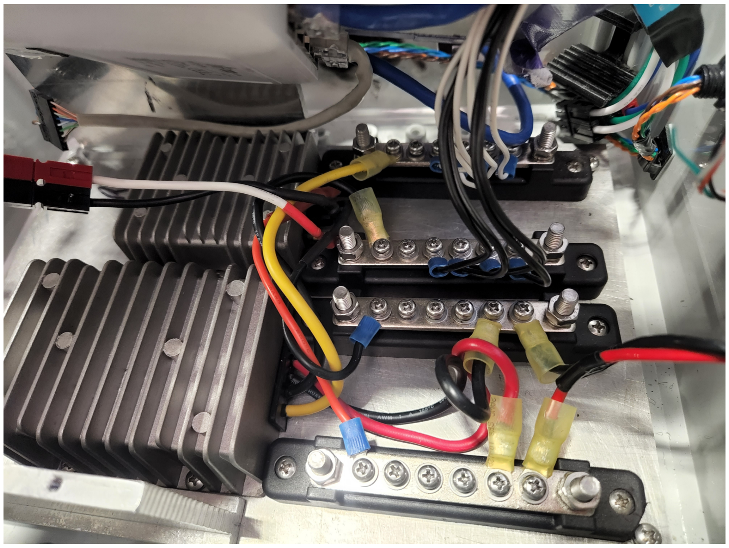


Figure 19: Bottom Plate

Top Plate (Side A)

This section of the internal components would need to be accessed the soonest if something goes wrong. On this level are two Pis, 8 ESCs, a distribution board for those ESCs, and the Pixhawk. This section is where the components necessary for control of ROV are held. This level of the electrical is also the most important so it is located further from the location where water would pool up in case of flooding.

The Top Plate (Side A) contains:

- Pixhawk: powered by the Pi3 at 5V its the brains of the ROV, it connects to the Pi 3 the ESC data wires, and the dynamic manipulator data wire. Built into it are multiple components necessary for navigation such as an accelerometer, magnetometer, and a gyroscope. It has a companion program that runs on the surface laptop for ease of control.
- Pi 3: takes 5V power to facilitate communication between the network and the pixhawk.
- Pi 4: takes 5V power to host software necessary for running the camera, and connects to the network.
- 8 ESCs: takes 24V power to redirect to the thrusters controlled by the pixhawk.
- Distribution board 2: This board is to connect the 8 ESCs smoothly to the 24V power rails in a way that allows each individual ESC to be replaced if needed.

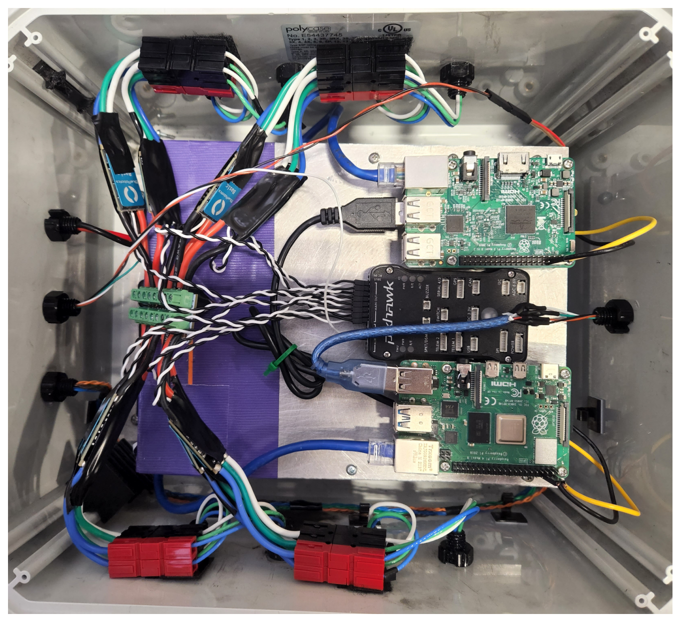


Figure 20: Top Plate (Side A)

Top Plate (Side B)

More power conversion is done on this plate as well for some of the more delicate components. This is also where the data from the computer goes once it enters the enclosure connecting to the network adapter that allows the computer to communicate with the two on board Raspberry Pis.

The Top Plate (Side B) features:

- 5V Converters (three): Has inputs from the 12V converter and converts those inputs to 5V which then powers the network switch, the Pi3 (Top Plate Side A), and Pi 4 (Top Plate Side A) all with direct connection to their own 5V converter.
- Network Switch: Powered from a 5V converter at 1A which then connects the data tether to two separate ethernet wires for Pi3 and Pi4 (Top Plate Side A).
- Distribution Board 1: Facilitates the connections between: the 12V converter output and the 5V converter inputs, the 12V converter outputs and the input power for the linear actuator, and the 5V regulator for the network switch so that we can use a resistor to supply the proper current RESISTOR
- Linear Actuator: Powered with 12V and uses PWM signal from the pixhawk to actuate the dynamic manipulator so that the ROV can interact with its environment.

Figure 21: Top Plate (Side B)

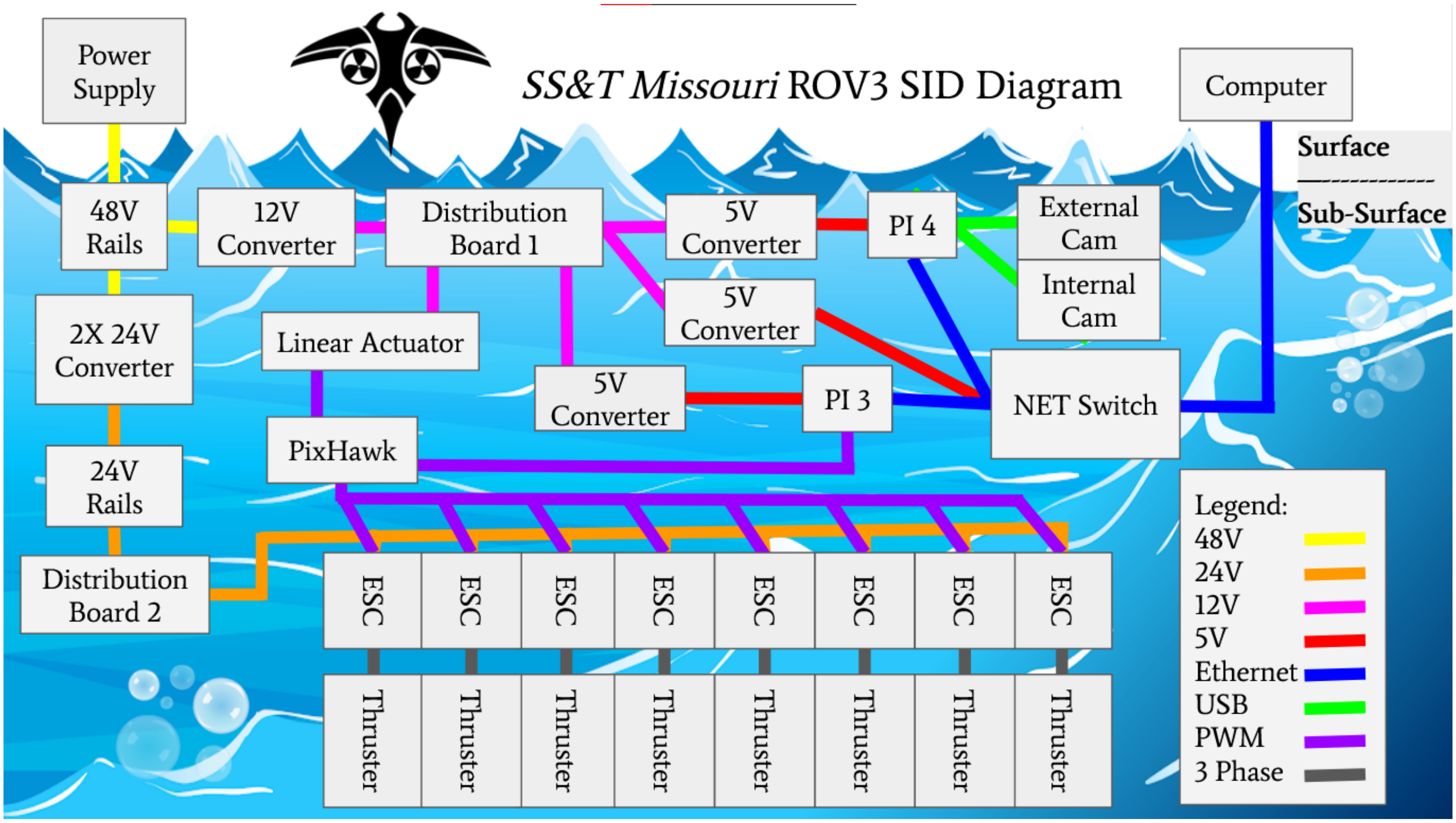


Figure 22: SS&T Missouri SID Diagram

Computing

The Computing Division of the Underwater Robotics Team is responsible for developing the software controlling the team's ROV, as well as programming the team website. This division works heavily with the electrical division to program circuit boards and troubleshoot the information flow of the ROV.

Organization

The computing division is organized with one lead member who manages and reviews projects, while also acting as a liaison between the division and the general leaders of the URT. Members of all skill levels are a part of the team and often allowed to choose their own projects on the team Trello board. However, in the event of deadlines, members may be required to put their work on hiatus to help on the more dire project.

The Computing Division meetings are held every Saturday at 6:00 PM into the evening depending on how much work is planned. Meetings were originally online in late 2021 and early 2022, but shifted into mainly in-person events held at the SDELC during February of 2022 and onward.

Most of the code used by our organization is stored on an open-source GitHub repository, allowing it to be archived for future years. Through this procedure, the team has access to code created as early as 2011 for land-based robotics competitions. Furthermore, the repository allows computing members to immediately see what other teammates are working on and give feedback, while also allowing members to work off of the most up to date version of our code. Computing resources such as pseudo code or tutorials are instead stored on the team's Google Drive, allowing members from other divisions to see what is planned.

Early Network Setup

Originally, the source code for the ROV was mainly programmed in C, though the setup code for the boards was written using the Arduino IDE. More hardcoded setup for the boards was performed using BLHeli Suite. To drive the main board in these early pool tests, a Teensy++ 2.0 was attached to the mainboard and connected to a surface board attached through USB to the team laptop. This setup was often bypassed when testing motors and ESC boards by creating a serial connection directly between the laptop and the ESC board, allowing the laptop to accept user console commands that are reflected on the ROV motors. Figures 1 and 2 show more information about the structure of our driver and ESC code respectively.

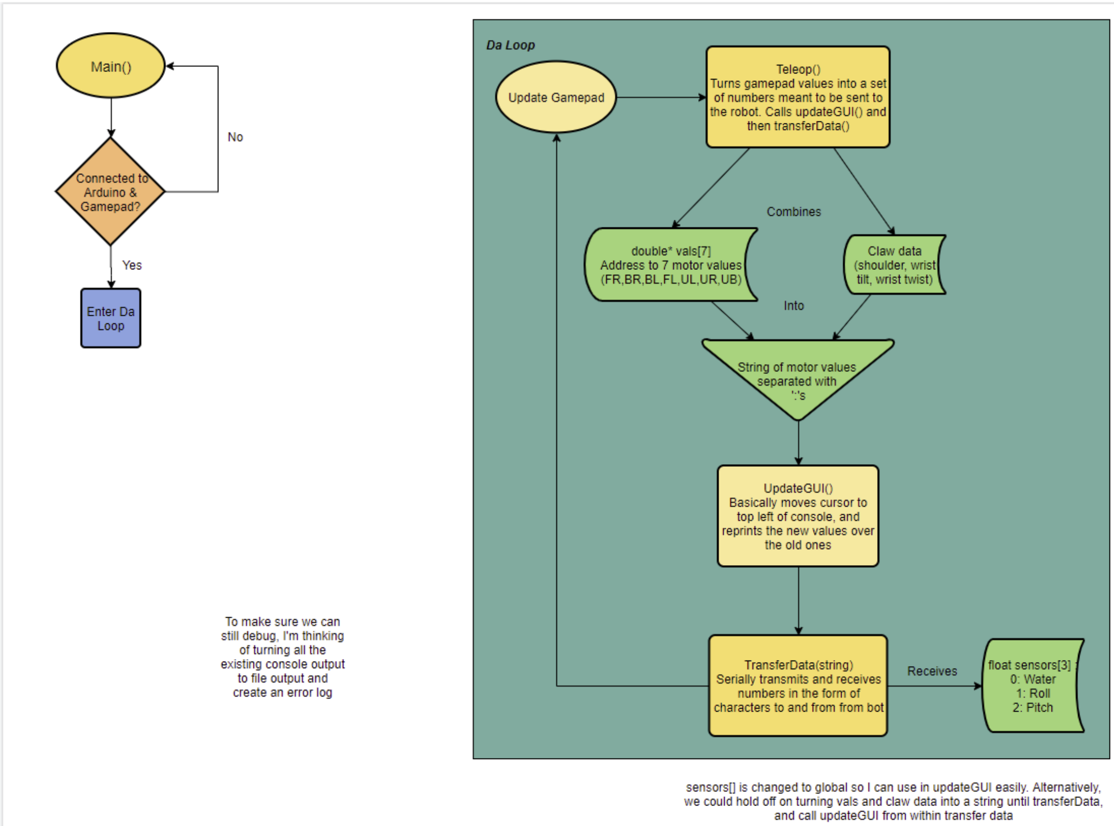


Figure 23: A flowchart showing the flow of the drive code for the ROV.

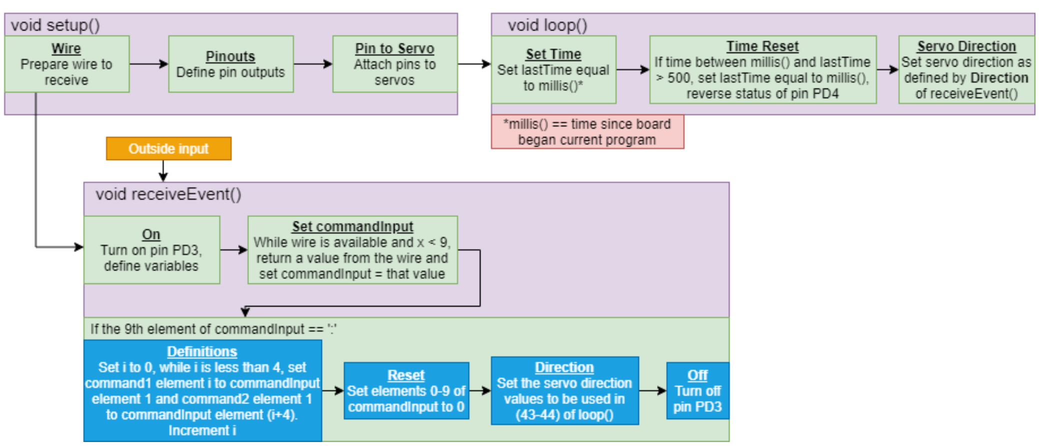


Figure 24: A flowchart representing the ESC board setup code

When the ROV was running through a pool test, a UI on the C console was used to keep track of the robot and catch errors. The UI constantly output an array representing controller inputs to the mainboard, which was then echoed back to the control station to verify that the mainboard is working properly. The mainboard also read sensors from the ROV through the attached tether and outputted this information to the driver code itself. These changes were not reflected in the UI as long as they are not critical.

Transition to ArduSub and the New Network

Throughout 2021 and even parts of 2022, we struggled quite a bit with our initial network setup. One issue was the use of recycled, complex designs from earlier years that few present team members were familiar with, making debugging difficult. In addition, while we were able to get individual motors responding to commands, we rarely had the entire setup working at once. Sometimes, the mainboard successfully echoed commands back to the drive station yet did not send those commands to the ESC boards; other times, the mainboard sent back nothing at all. Most disturbingly, there were several tests where the mainboard received legible commands yet sent back completely corrupted data.

In March 2022, the team transitioned to our current network setup based on the ArduSub project by BlueRobotics. Instead of relying on Arduino boards, this new setup instead relies on the Pixhawk 2.4.1 connected through USB to a Raspberry Pi 3, a Raspberry Pi 4, and the driver laptop running QGroundControl. All of these devices communicate over an Internet Protocol network (IP network) through a central network switch located on the ROV. This network allows all connected devices to communicate with each other, sometimes concurrently, without issue.

The Pixhawk is used to control motors via ESCs while acting as an accelerometer, compass and gyroscope, while the Pi 3 acts as the main companion computer running ArduSub firmware. The Raspberry Pi 4 handles vision and object recognition and is explained in further detail in the next section.

During pool tests, we use a BlueRobotics Fathom ROV Tether to connect a laptop running QGroundControl to a network switch on the ROV via Ethernet. This network switch is connected to both the Pi 3 and Pi 4 through shorter Ethernet cables. The Pi 4 streams camera data back to the surface while also hosting a server that the Pi 3 can connect to for vision data. The Pi 3 sends and receives information from the Pixhawk through a MicroUSB connection. Finally, the Pixhawk sends the now processed commands to the eight ESCs connected to the motors of the ROV.

Object Recognition

In autonomous events, the ROV utilizes a Raspberry Pi 4 running multiple custom built OpenCV algorithms to track and map objects when necessary. The ROV features a web dashboard to easily add and configure cameras, monitor system status of the raspberry pi (like CPU temp and network throughput), and view program console output.

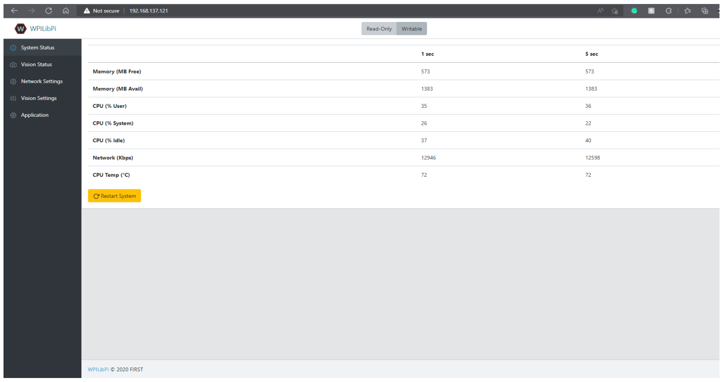


Figure 25: Web dashboard for managing pi status.

Our vision program also communicates back to the surface with a highly configurable user interface that allows the driver to select which vision algorithm they require and adjust its parameters using buttons and sliders. This dashboard also displays a live stream of the camera feed with an overlay of what the algorithm is currently tracking. The dashboard and program automatically start when the raspberry pi is powered on. All of this allows us to quickly receive a camera stream and configure our vision program without needing to input commands or change any code. Ultimately, everything is user-friendly and driver-proof.

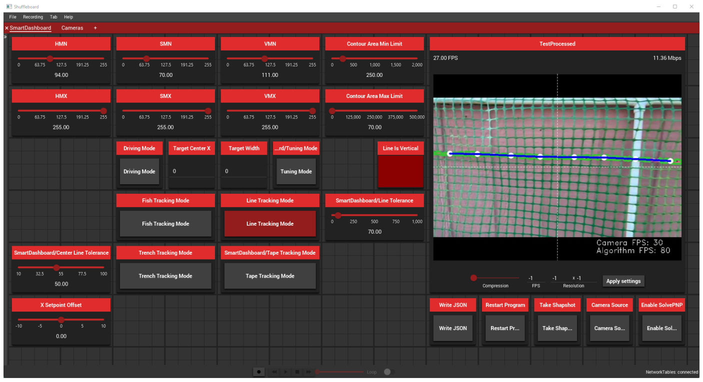


Figure 26: Vision user interface (line tracking)

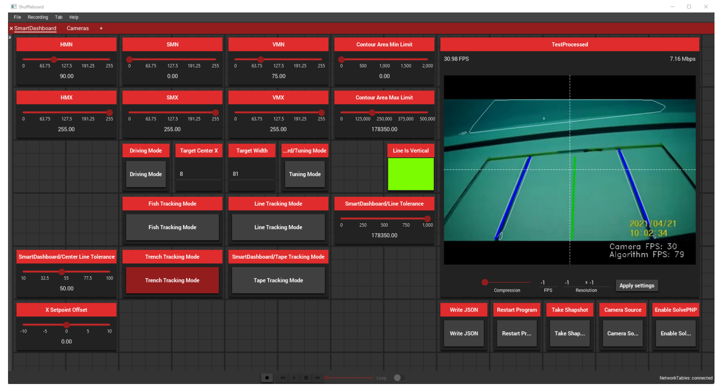


Figure 27: Vision user interface (shipwreck tracking)

Finally, our software is able to take a video input and perform a dead fish detection on the given video. This software is based on the YOLOv3-tiny algorithm. The reason for this algorithm is that it produces results in a much faster manner than other algorithms; more precisely it processes 220 frames per second (FPS), whereas other algorithms that we have considered process less than 60 FPS. YOLOv3-tiny algorithm is trained to detect any fish and it is used as a benchmark for our final model. The fish datasets used for training, testing, and validation are from Open Images Dataset V6 + Extensions (https://storage.googleapis.com/openimages/web/index.html). The training dataset consists of 11,456 training images. Additionally, we collected more data on fish from practice videos and labeled dead and alive fish. This additional data is utilized for transfer learning from our original YOLOv3-tiny model. We again used the same algorithm to differentiate between dead and alive fish, where dead fish has a green bounding box around it.

Outreach

Website

The Missouri S&T Underwater Robotics Team website, underwater.mst.edu, serves as the “home base” of sorts for people who are interested in learning more about our team. Originally, it served as a blog to document our journey, but after careful examination and revision, it has blossomed into an informative hub where one can find everything they need to know about us and what we do.

The 2021-22 build season showed a complete overhaul to the team website. Designed in Wordpress, this site is now something the team proudly advertises to those looking to learn more.

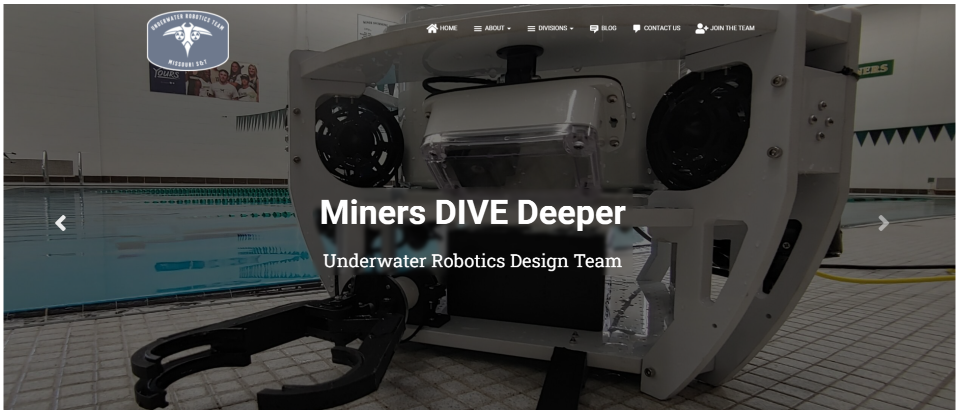


Figure 28: The current underwater.mst.edu homepage, designed by members Nathan Hart and Jason Xu.

Campus Outreach

The Missouri S&T Underwater Robotics Team participated in many campus outreach events over the course of the year. The team members provided tours of the Student Design Center to high school students to show them the entire facility. The team was able to speak about the challenges that are faced with the competition and the real world applications of ROVs.

The Team participated in Kummer Vanguard Scholarship days. During this time, prospecting students would get the opportunity to meet with Design Teams. Members spoke with the prospective students about the Team, ROVs, the challenges that are discussed in MATE ROV. These Scholarship days brought members to the team and brought awareness to the challenges in MATE ROV.

On March 5th 2022, the Team attended the FIRST Tech Challenge Missouri State Championship in Rolla, MO. Members were able to interact FIRST members about MATE and the team.

The team was invited to present their research to the Academy of Mechanical and Aerospace. This resulted in a grant being awarded for them. The same evening, the team had the privilege to attend the Miner Alumni Association to present our plans for the *SS&T Missouri*. During the event, they had a chance to speak with Chancellor Mo Deghani about progress made.

USS Missouri

Throughout the course of the semester, the team established a connection with the Battleship Missouri Memorial, in Pearl Harbor, Hawaii. The *USS Missouri* served as a source of inspiration for our own *SS&T Missouri*. A plaque was designed to connect the two, and to provide a lasting legacy of both the “Mini Mo” and the “Mighty Mo” within the Student Design Center at Missouri S&T.

Safety

Safety Philosophy

The Underwater Robotics Team of Missouri S&T is committed to having safety as a top priority. Within the student design center, the team follows 5S principles to create and maintain a usable workspace. At the beginning of each build season, our work area is sorted, with essential items being placed in designated areas. It is encouraged to keep the bay in a clean and tidy state, and our team has an appointed 5S Coordinator to ensure the standardization and sustainment of these practices.

Figure 29: The 5S Principles. Credit: 5stoday.com

The team has followed the Missouri University of Science and Technology's policies regarding COVID-19 since its first conception. Currently, a sign-in/sign-out system is utilized to minimize possible infections through contact tracing.

ROV Safety Features

The SS&T Missouri is fully waterproofed using epoxy, certified connectors, and a Polycase enclosure to house our electrical components. This intense waterproofing was a large hurdle for the team to jump, and was tested thoroughly throughout the season. This waterproofing ensures that our ROV is protected from short-circuits, and that our members are safe both on land and in the water.

The ROV has a camera housed inside the electronics enclosure to allow us to see leaks in real-time, and to allow for immediate response in case of a leak.

Internal automatic circuit breakers are present with each of our power converters. These circuit breakers will turn off if the amperage inside the electrical system gets too high, in order to prevent possible overheating.

Safety Checklist

Pre-Deployment

- ☐ Power is off
- ☐ Deployment area is clear
- ☐ Required crew is present and prepared
- ☐ Tether is securely connected and other connections are secured tightly
- ☐ Enclosure sealed properly
- ☐ Ballast is properly secured and distributed

Starting ROV

- ☐ Power supply is plugged in and on
- ☐ Control station powered and on
- ☐ Video feeds are live and clear

Deployment

- ☐ ROV constantly monitored by surface crew and pilot
- ☐ Camera checks to ensure no water leaks

- ☐ ROV is armed when in motion and disarmed when not moving
- ☐ Test thrusters and manipulator

Communication Loss

- ☐ Disarm ROV
- ☐ Check if surface connections are secure
- ☐ Check internal camera for water
- ☐ Re-arm ROV and test communication
- ☐ If lack of communication persists:
    - ☐ Disarm and power down ROV
    - ☐ Use tether OR diver to surface ROV and check internal systems

Return to surface

- ☐ Pilot surfaces and disarms ROV near crew
- ☐ Crew members carefully extract ROV from water and secure it
- ☐ ROV is powered down, control station is unplugged and powered off

Logistics

Company Organization

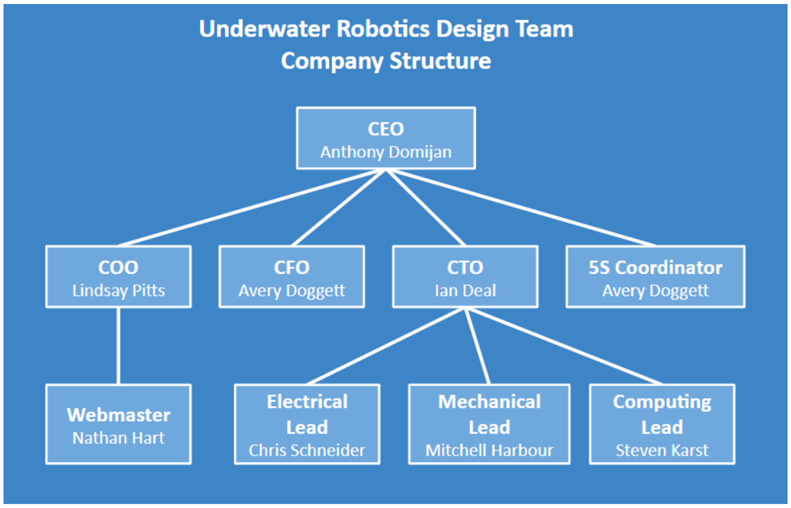


Figure 30: Company structure chart

Our team consists of a C-Suite, and four divisions, each with a leading member. In the C-Suite, the Chief Executive Officer (CEO) oversees all operations of the company, followed by the Chief Operational, Financial, and Technical Officers, who oversee logistics, finances, and ROV construction respectively. The 5S Coordinator ensures that our workspace is functional and follows all 5S principles, with an emphasis on safety. Our Webmaster handles all aspects of the team website, underwater.mst.edu.

Schedule and Timeline

The team's project schedule was created in Google Docs, and was kept within the team Google Drive to allow for easy access for all team members. While the CEO and CTO jointly create the year's timeline, the division leads are responsible for ensuring all projects are completed on time. A full schedule for the '21-'22 build season can be located within Appendix B.

Collaborative Workspace

The Underwater Robotics Team is housed within the SDELC (Student Design and Experiential Learning Center) at the Missouri University of Science and Technology. The SDELC houses 18 other teams, who all focus on their own engineering facets. This encourages collaboration between students of many different backgrounds and disciplines, and gives members the opportunity to learn from other engineers and scientists.

The design center contains a full machine shop, composites room, electronics lab, and computer lab. Our members strived to utilize all of these resources to their full potential, and were ecstatic to have access to utilities such as 3D printers, a waterjet, and soldering irons.

All documents, files, and information within the team is compiled on a google drive, which all members have access to. This allows for quick access when needed, as well as a fast way to share files with others. A second drive, which only officers can access, holds sensitive information for the team.

Budget

Because this is our first year attending competition, expenses were tricky to plan and manage. The '21-'22 season also saw our first time completing a vehicle from start to finish.. A full budget for the *SS&T Missouri* can be found within Appendix A.

Travel

Below is a table containing the estimated and current actual costs for travel to and from the 2022 MATE ROV competition. Rental car costs are not set in stone, and can only be estimated until the day of travel.

Item	Estimated Cost	Actual (Projected) Cost
Hotel	$2,400.00	$2,600.00
Air Travel	$3,000.00	$5,100.00
Rental Car	$525.00	$525.00
Total	$5,925.00	$8,225.00

Table 1: Estimated vs actual cost

Conclusions

Attending MATE ROV with a functioning vehicle is a humongous leap for our team. After years of struggling, we are proud to be where we are, and are ecstatic with the progress made this year.

Logistical elements such as scheduling and budgeting are where our team struggles the most. In the future, we aim to have a timeline created at the beginning of the season, and to stick to it as weeks go by. Each division also needs improvement on creating their own schedule to work with.

In the future, the Missouri S&T Underwater Robotics Design Team strives to improve our designs and builds to an even higher standard. We plan to reduce the size of the main enclosure to lower the weight of the ROV, implement a better, more efficient electrical system, and explore the possibility of adding sonar to the ROV.

Acknowledgements

Thank you to the following members of the community for supporting our team throughout the 2021-2022 build season:

- Odyssey Scuba (Diving Equipment)
- Multirotor Design Team (Materials, Mentoring)
- Rocket Design Team (Materials)
- Combat Robotics Design Team (Materials)
- Battleship Missouri Memorial
- Stanley Domijan (Donation)
- Austin Pipkins (Donation)
- Student Design and Experiential Learning Center (SDELC)

References

MATE ROV Competition Website, *https://materovcompetition.org/.*
Blue Robotics, https://bluerobotics.com/.
ArduSub, https://www.ardusub.com/.
"What Is 5s?" 5S Today, https://www.5stoday.com/what-is-5s/.

Appendices

Appendix A: Budget for the *SS&T Missouri*

Item	Quantity	Cost per item	Total Cost	Acquisition
1.78mm X 8.73mm (NBR) Buna-N 70 Duro Metric O-Ring	2	$ 0.25	$ 0.50	Purchased
2.54mm female headers (blue)	15	$ 2.50	$ 37.50	Purchased
2.54mm female headers (white)	15	$ 2.50	$ 37.50	Purchased
6 Terminal Bus Bar	6	$ 12.99	$ 77.94	Purchased
60ml syringe with luer lock fitting	1	$ 9.99	$ 9.99	Purchased
Adufruit Protoboards	10	$ 8.95	$ 89.50	Purchased
Blue Robotics 25 meters of power cable	1	$ 450.00	$ 450.00	Purchased
Blue Robotics Basic ESCs	8	$ 30.00	$ 240.00	Purchased
Blue Robotics Cable Repair Kit	1	$ 20.00	$ 20.00	Purchased
Blue Robotics Low-Light HD USB Camera	1	$ 99.00	$ 99.00	Purchased
Blue Robotics Spare Bulkhead O-Ring Set	3	$ 3.00	$ 9.00	Purchased
Blue Robotics WetLink Penetrator 8.5mm LC	1	$ 12.00	$ 12.00	Purchased
Blue Robotics WetLink Penetrator Spare Seals 4.5mm	1	$ 18.00	$ 18.00	Purchased
Blue Robotics WetLink Penetrator Spare Seals 6.5mm	2	$ 18.00	$ 36.00	Purchased
Blue Robotics WetLink Penetrator Spare Seals 7.5mm	1	$ 18.00	$ 18.00	Purchased
Blue Robotics WetLink Penetrator Spare Seals 8.5mm	1	$ 18.00	$ 18.00	Purchased
Blue Robotics WLP-M10-8.5-LC	1	$ 12.00	$ 12.00	Purchased
BlueRobotics WetLink Penetrator 6.5mm Low Clearance	1	$ 12.00	$ 12.00	Purchased
Brass Body with Lever Handle—Straight (47865K27)	1	$ 58.54	$ 58.54	Purchased
Cllena DC 48V Step Down to 24V Reducer Conveter	2	$ 49.99	$ 99.98	Purchased
LEDMO 48V Step Down to DC 12V	1	$ 20.99	$ 20.99	Hold Over
Linear Actuator (100mm Stroke, 100:1 Gear Ratio, 12V)	2	$ 90.00	$ 180.00	Purchased
McMaster Carr Sure-Grip Aluminum Cord Grips (70175K1)	1	$ 18.11	$ 18.11	Purchased
McMaster Carr Sure-Grip Aluminum Cord Grips (70175K2)	1	$ 19.00	$ 19.00	Purchased
McMaster-Carr 18-8 Stainless Steel Socket Head Screw	1	$ 14.74	$ 14.74	Purchased
McMaster-Carr 18-8 Stainless Steel Socket Head Screw M3 x 0.50 mm Thread, 55 mm Long	1	$ 10.36	$ 10.36	Purchased
McMaster-Carr 18-8 Stainless Steel Socket Head Screw M4 x 0.70 mm Thread, 85 mm Long	1	$ 7.69	$ 7.69	Purchased
McMaster-Carr Marine Grade Polypropylene sheets 24x24in	1	$ 54.93	$ 54.93	Purchased
McMaster-Carr Marine Grade Polypropylene sheets 24x48in	1	$ 91.55	$ 91.55	Purchased
McMaster-Carr Multipurpose 6061 Aluminum 1"x2' Bar Stock	1	$ 27.05	$ 27.05	Hold Over
McMaster-Carr Multipurpose 6061 Aluminum 1/8"x6" Sheet	1	$ 58.26	$ 58.26	Hold Over
McMaster-Carr Multipurpose 6061 Aluminum 2"x2" Bar Stock	1	$ 13.70	$ 13.70	Hold Over
McMaster-Carr Multipurpose 6061 Aluminum 3"x3' Rod	1	$ 231.39	$ 231.39	Donated
NETGEAR 5-Port Gigabit Ethernet Unmanaged Switch (GS305)	2	$ 32.15	$ 64.30	Purchased
Oil bladder for profiling float	1	$ 7.99	$ 7.99	Purchased
Panel mount Connectors	2	$ 10.00	$ 20.00	Purchased
Panel Mount Socket Connectors	2	$ 8.53	$ 17.06	Purchased
Panel mount socket connectors 3 prong	8	$ 9.73	$ 77.84	Purchased
PixHawk	1	$ 45.00	$ 45.00	Donated
PolyCase ZQ-141206 Outdoor Electrical Box	1	$ 69.08	$ 69.08	Purchased
Proshopping DC 12V Step Down	3	$ 11.99	$ 35.97	Purchased
Raspberry Pi 3	1	$ 179.99	$ 179.99	Purchased
Raspberry Pi 4	1	$ 159.99	$ 159.99	Purchased
Sea Pearls 1lbs Soft Dive Weight	1	$ 10.27	$ 10.27	Purchased
Sea Pearls 2lbs Soft Dive Weight	3	$ 11.95	$ 35.85	Purchased
Sea Pearls 5lbs Soft Dive Weight	2	$ 22.50	$ 45.00	Purchased
Socket panel Mount connectors 3 prong	8	$ 8.58	$ 68.64	Purchased
sparkfun IMU	10	$ 17.50	$ 175.00	Purchased
Through-Wall Straight Connectors, Female Threaded Pipe (36895K145)	1	$ 53.22	$ 53.22	Purchased
		Total	$ 3,168.42	

Appendix B: Build Schedule

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Key
			Fall Semester					
8/1-8/7								School Break
8/8-8/14								End of Semester
8/15-8/21				O Week Tours				Mechanical Event
8/22-8/28		CLASS STARTS				Enclosure Designed	Enclosure Review	Electrical Event
8/29-9/4								Computing Event
9/5-9/11	Labor Day		Frame Design Complete	Frame Review				PR Event
9/12-9/18		Board Design Complete						URT Event
9/19-9/25								Pool Test
9/26-10/2			Design Review 2			Fall Break		
10/3-10/9		Frame Design Complete						
10/10-10/16								
10/17-10/23	Manufacturing Done							
10/24-10/30	ROV Ready to Test					Order Boards		
10/31-11/6				Testing				
11/7-11/13	Boards Populated			Board Testing				
11/14-11/20								
11/21-11/27				Thanksgiving				
11/28-12/4							***ROV FULLY COMPLETE***	
12/5-12/11			Dead Week					
12/12-12/18			Finals					
			Spring Semester					
1/23-1/29								
1/30-2/5		Manipulaor Testing						
2/6-2/12								
2/13-2/19		Autonoumous Testing		Manipulator Redesign		Spring O Rama		
2/20-2/26								
2/27-3/5		Autonoumous Testing		Manipulator Redesign				
3/6-3/12								
3/13-3/19					Saint Pat's Break			
3/20-3/26								
3/27-4/2			Spring Break					
4/3-4/9								
4/10-4/16								
4/17-4/23								
4/24-4/30								
5/1-5/7				Dead Week				
5/8-5/14				Finals Week	Shoot and Submit Video			
5/15-5/21								
5/22-5/28					MATE Documentation Due			