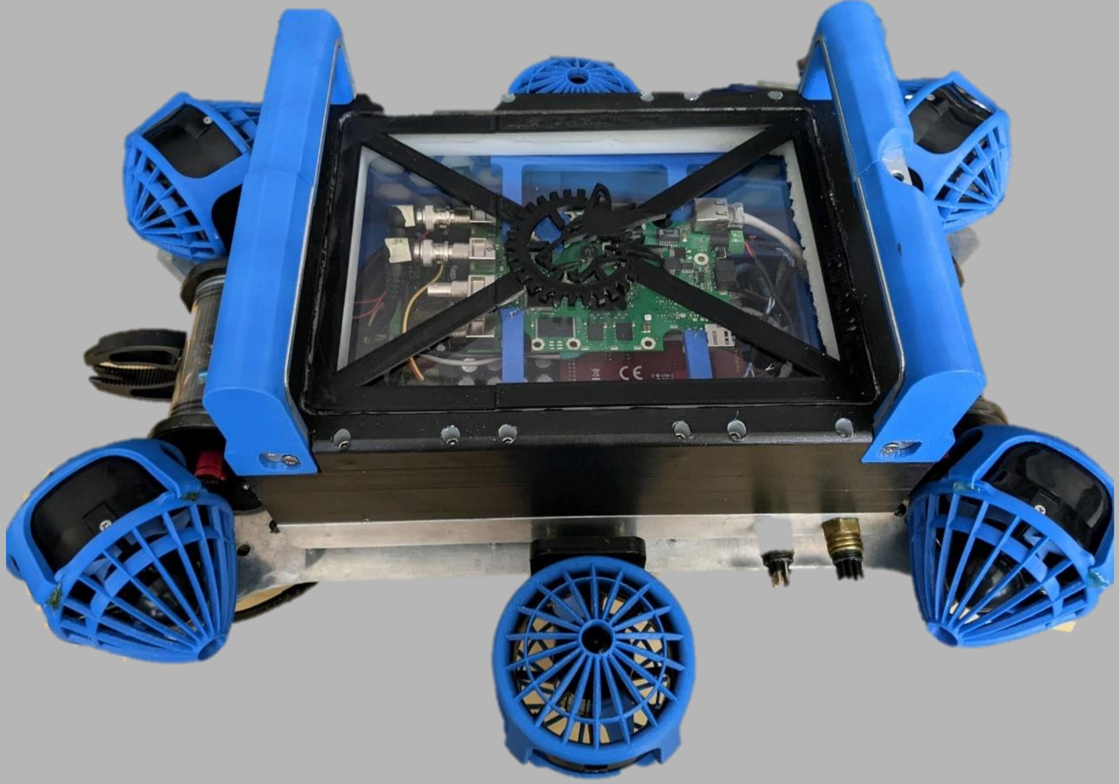

SEAWOLF X: EXPLORER

Product of S.U.R.E located in Wesson, Mississippi, USA

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Abstract: The Underwater Pack

Seawolf Underwater Robotics Engineering (S.U.R.E.) is a vibrant and innovative company, who recognizes the value of improving the state of ocean health for the planet's future. To make steps toward this endeavor, S.U.R.E has dedicated itself to producing a suitable ROV to address subjects affecting the global community: combating climate change, providing free energy, and feeding the growing population. Located in Wesson, Mississippi, S.U.R.E is a company with nine years of experience and history of setting itself apart from its larger funded competitors. This year's team has created a remotely operated vehicle capable of replacing inter-array cables, inspect an offshore agriculture, and recover floats. With improvements on Seawolf IX, Seawolf X is now equipped with a high-density polyethylene top, clear acrylic window, fiber glass circuit board, and handles for easier retrieval and transport. S.U.R.E's team includes employees who specialize in programming, electronics, and design. These team assets come together to make a ROV that meets the request for proposal and MATE standards. Seawolf X's tooling is solely but efficiently composed of a manipulator for marine renewable energy, offshore agriculture, and blue carbon task. Every step of the way, safety measures were taken to ensure that Seawolf X presented no danger to the operators or the environment. Seawolf X was a cumulative effort that was carried out by a staff passionate to the state of the environment and society.

This technical writing represents the desire, accomplishments, and struggles of the S.U.R.E. company in attempting the request for proposal.

Figure 1 S.U.R.E. 2022 Employees: 2nd Row Left- Paige Shedd, Cade Romano, Isaac Ebbers, Joshua Sauls Roger Rushing, Nathan Spears, Mr. Williamson, 1st Row Left-Gracee Warren, Neziah Smith, Dr.McKone, Megan Arnold, Greyson Graves, Chris Smith

Design Rationale

The design of the Seawolf X is mainly gleaned from the previous Seawolf IX. Seawolf IX was a tremendous success in our company’s history, but some factors needed improvement. This year, the team shot for a design that was not only practical but aesthetically pleasing.

This ROV was made with the same sleek design, but changes were made to give more functionality and accessibility to the vehicle and its components. One of these changes included increasing the height of the roof to allow a more spacious area when working on the electrical or mechanical elements inside of the ROV. This extra space was also vital to the factor of buoyancy. It successfully aided in creating a neutrally buoyant property to Seawolf X. An acrylic window at the top of Seawolf X allows for a visual pathway to the indicator lights (Figure2) on the main board, equipping the team with an improved ability to monitor the functions of the ROV. The addition of handles to the design improved the team’s ability to transport the vehicles as well as created an area for a tether relief, which is crucial to the safety of the vehicle. Seawolf IX had a problem with excess heat interrupting the software. The new ROV design addresses this by placing the power board directly on the aluminum base, which dissipates the heat from the inside into the water.

All these design changes come together to make a Seawolf X similar but distinctively different from Seawolf IX.

Figure 2: Indicator Light Through Acrylic Window

Modeling

While original component designs from Seawolf IX used in the current ROV were developed in SolidWorks and Blender, Seawolf X was primarily designed in Fusion 360 (Figure 4), a CAD program with a near unlimited toolkit to allow full freedom when designing the ROV. The entirety of the ROV, from the main body to the thrusters and manipulator, was first modelled using SolidWorks and Blender programs. They were reimagined in Fusion 360 before physical construction began. Fusion 360 has the ability to transfer files from a cloud system, which made it simpler for the engineer team to access dimensions of Seawolf IX shared by the original design team. Using this software allowed them to fully account for components needed for construction and assembly of the Seawolf X before having to purchase materials that could potentially go to waste. The S.U.R.E. company realized the near limitless abilities that CAD software provides and placed great importance on learning how to use such programs. Fusion 360 has been a monumental tool in their journey to create efficient and improved streamlined drone designs for various uses.

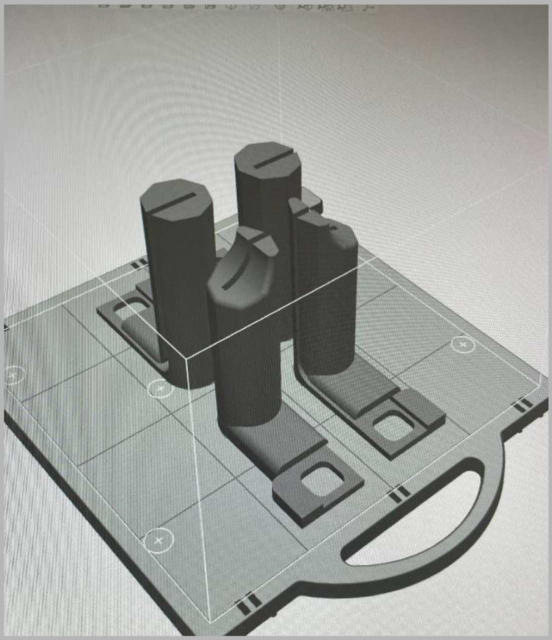


Figure 3: Feet Translated in the 3D Printer

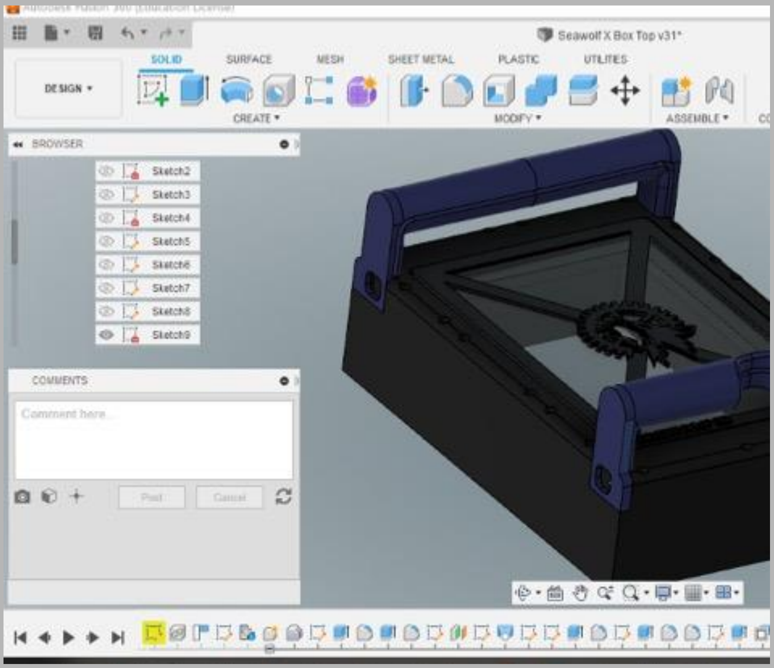


Figure 4: HDPE Encasement in Fusion 360

Material and Components

S.U.R.E. uses the best materials within its access. Many components were bought or reused; others were created from acrylonitrile butadiene styrene (ABS) by a 3D printer (Figure 6). The outside of Seawolf X consists of an aluminum base, CCTV camera, high density polyethylene (HDPE) encasement, acrylic window, ABS feet, handles, thruster guards, and Blue Robotics T100 thrusters. Among the items reused were the aluminum base and thrusters. These items were reused due to the similarity to the present design in addition to the cost efficiency of retaining them.

The organs included an ABS abdominal wall and shelf housing operational boards which include the camera board, main board, and power board. The camera board was originally bought but was reused for Seawolf X. The mainboard was manufactured at Advanced Circuits but designed by a previous year's team. The power board was specifically created for Seawolf X because of the need for heat sinks which were not present on the previous board. Seawolf X is 67.33 cm long, 46.76 cm wide, 30.45 cm tall and a mass of 13.5 kg.

Figure 5: Early Seawolf X

Figure 6: 3D Printer Working on Feet

Electronics

Camera Board


Figure 7: Camera Board on Abdominal Shelf

The video encoder board (Figure7) was purchased and removed from its casing to reduce weight and size. It is powered via the main board and has two cameras connected to it. The video encoder allows for display of the ROV's two cameras. The encoder also contains a slot for a micro-SD card that permits recording and downloading of video footage from the ROV.

Main Board

The main four-layer board (Figure 8) was designed in house, manufactured by Advanced Circuits and is responsible for receiving the supplied 48V DC and filtering the incoming voltage. It also houses the main onboard microcontroller, a Diligent ChipKit Max32. Other items found on this board are an Ethernet Switch, Razr IMU, connections for 4 temp sensors, two connections for servo outputs, connection for the Blue Robotics temp/pressure sensor, lighting outputs, actuator controls, and an ambient temperature sensor. This board is powered by the 5V and 12V DC to DC converters found on the power supply board. It has a 30A fuse for incoming voltage and fuses for both the 5V and 12V supplies.

Figure 8: Main Board

Power Board

The Seawolf X power board was created this year by our exemplary electronics team. Another power board was required because excess heat caused interruptions in the software of Seawolf IX. Heat sinks where a proportion of the solution but could not be attached to the original board (Figure 9). A whole new board was designed around DC/DC converters containing heat sinks (Figure 10). To further improve the other portion of the heating problem, Seawolf X and the board were designed for direct contact between the heat sinks and aluminum base plate (Figure 11) causing heat to be absorbed and displaced away from the innards of the ROV. 48V enters and is converted to 12V; this lower voltage was required to then be converted to 5V. The 12V are needed for the camera and 5V are used in the servo. Three of the five converters where allotted to the thrusters. We needed 15V as output to run the thrusters and used Rup= (16400/12-3.28)-750=1130Ω to calculate this offset.

Figure 9: Power Board Without Heat Sink Created in 2020

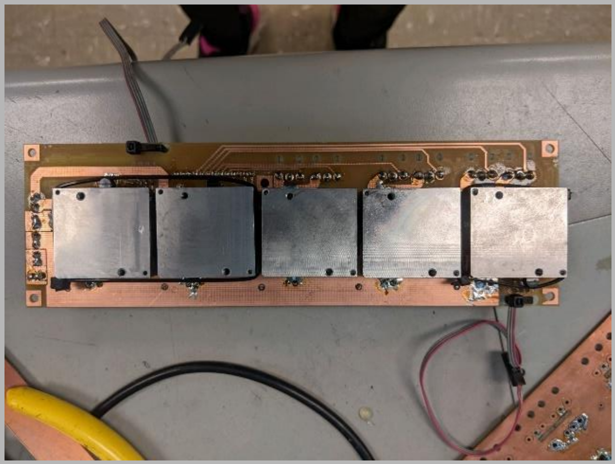


Figure 10: Power Board Bottom Side Heat Sink

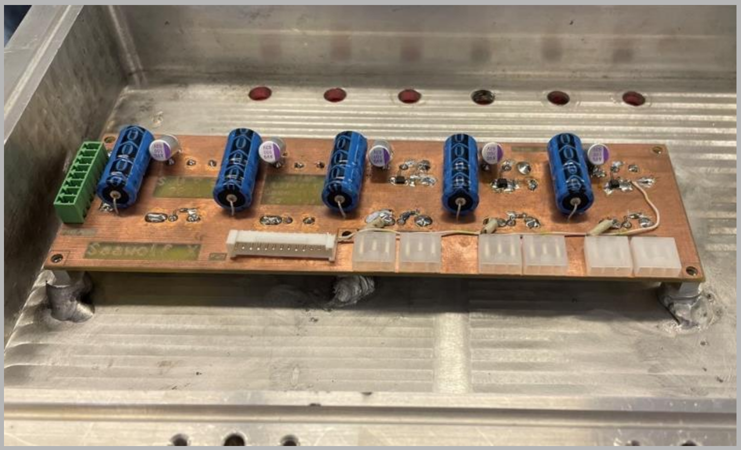


Figure 11: Power Board on Aluminum Base

Tether

The Seawolf X’s tether (Figure12) provides power, GND, and Ethernet communications to the robot via 8 and 3 pin Seacon bulkheads. There is a 30A in-line fuse within 30 cm of the surface power supply. Both ends of the tether have strain relief provided by carabineers secured to Seawolf X and the control station. The network router distributes standard Ethernet connectivity to all the main parts of the control system. The company uses an Outland’s Technology tether, which is neutrally buoyant and durable enough to withstand strong currents and water pressure.

Figure 12: Tether

Control Systems

Seawolf X’s surface electronics equipment (Figure 12-14) is comprised of a TV (1), a laptop PC (2), a network router where the components communicate (3), an Outland Technologies tether (4), an Axis IP video decoder (5), and ethernet cables (6). The S.U.R.E company’s focus to maintain quick and convenient setup and breakdown process to restrain from overcomplicating the surface control area. As a result, the probability of errors and damage to the control systems and equipment are significantly reduced.

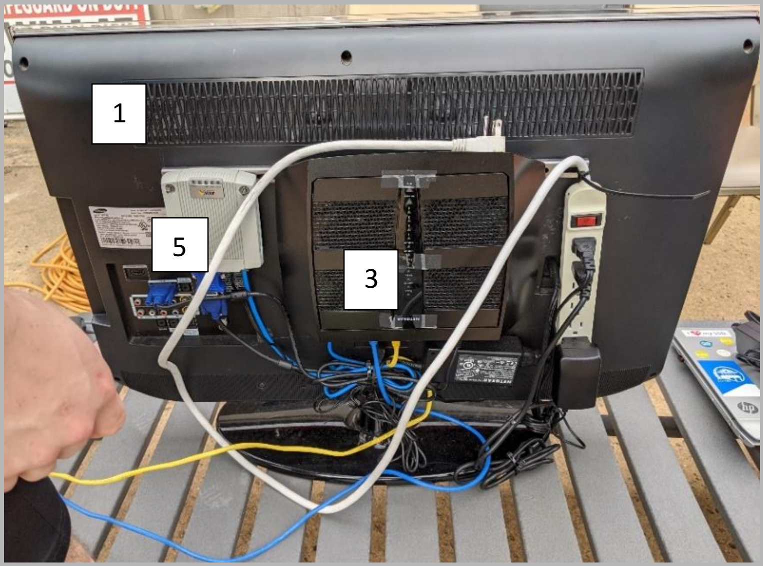


Figure 13: Control Systems

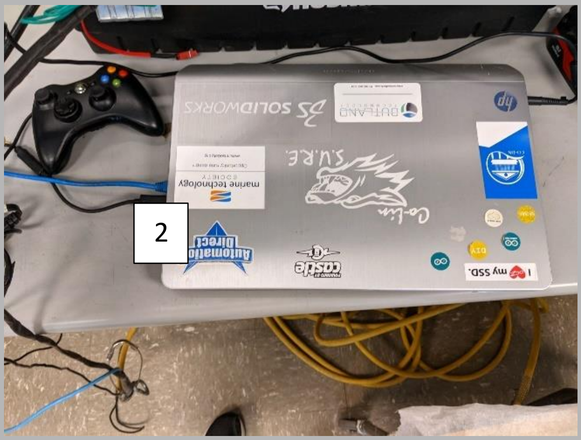
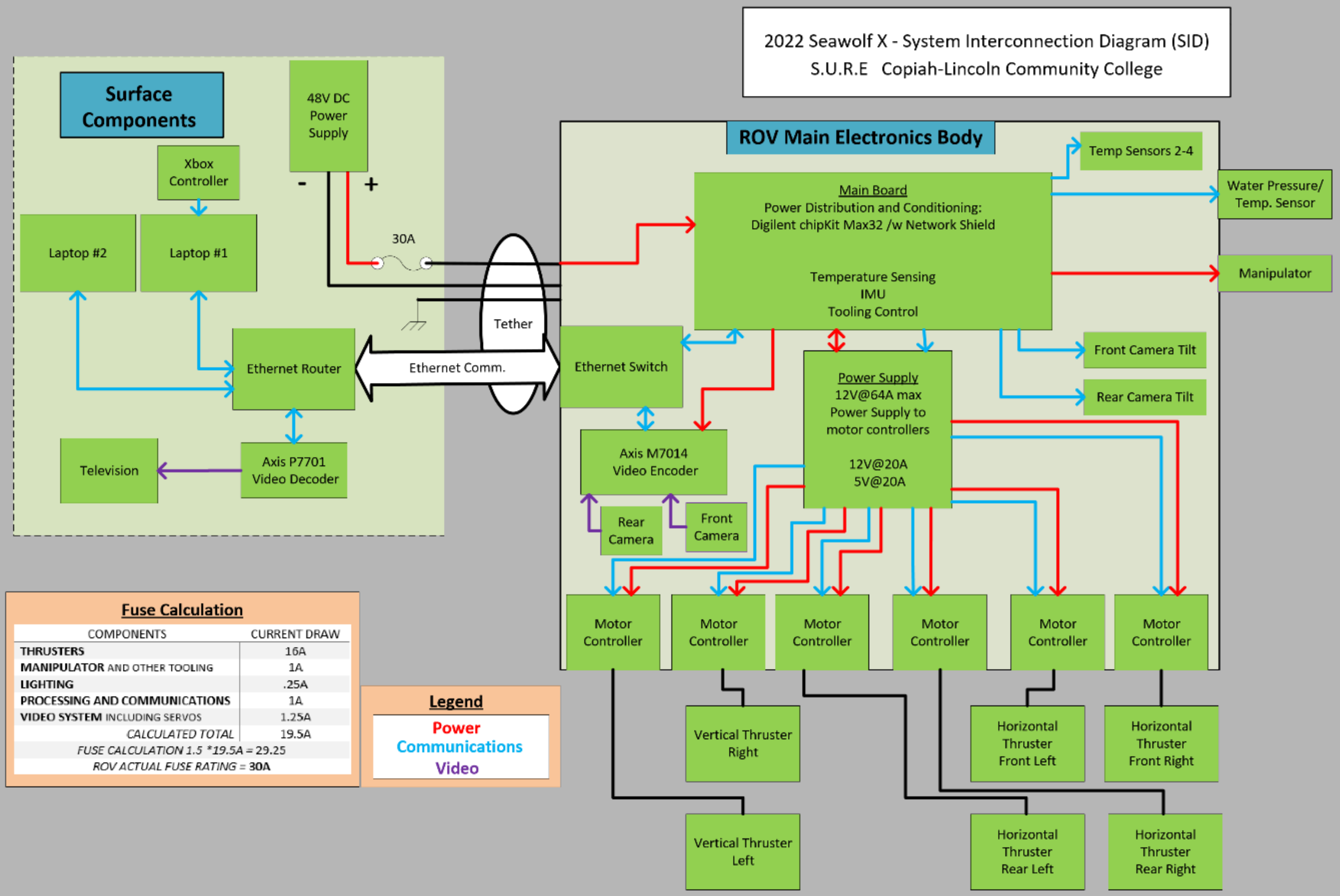


Figure 14: Laptop



Fuse Calculation

COMPONENTS	CURRENT DRAW
THRUSTERS	16A
MANIPULATOR AND OTHER TOOLING	1A
LIGHTING	.25A
PROCESSING AND COMMUNICATIONS	1A
VIDEO SYSTEM INCLUDING SERVOS	1.25A
CALCULATED TOTAL	19.5A

*FUSE CALCULATION 1.5 *19.5A = 29.25*

ROV ACTUAL FUSE RATING = **30A**

Tooling

Figure 15: Blue Robotics Newton Subsea Gripper

Figure 16: Handles Being Connected Using Aluminum Bar

Figure 17: CCTV Cameras

Figure 18: Honeycomb Feet

Manipulator

The most prominent tool that Seawolf X is equipped with is the Blue Robotics Newton Subsea Gripper (Figure 15). The gripper opens to a 6.19 cm diameter and is pressure tested at depths up to 299.9m. The company decided to focus on mastering the control of the tool in order to complete missions effectively. The Gripper is placed at the front and slightly to the right on Seawolf X, under the front camera. Its placement near the camera allows it to be in the camera’s field of view, which is ultimately beneficial to the driver. This allows the driver to see what he or she is doing with the manipulator. A manipulator mounting bracket was added to give the manipulator more stability. Due to its versatility, the manipulator is a simple and user-friendly tool that will play a crucial part in completing missions.

Thruster

The Seawolf X features six Blue Robotics T100 Thrusters (Figure 19) placed around the base plate of the ROV. Each motor is run on an individual DC to DC converter due to current limitations. The motors run on 15V DC which is supplied to them via the converters. Each motor is capable of drawing 11.5A, which is 0.5A less than the output of a converter. The motor output is software limited to decrease current draw to a total of 16A for all 6 thrusters. A power budget was calculated using P=I*V=48V*30A, providing the total power usage allowed for the robot. This helped the company decide that these motors could be effectively used. The thrusters are compact and work well with the small size of the robot; one thruster weighs only 120g in water. The thrusters' ability to propel in two directions gives the Seawolf X total freedom to travel in any direction and provides the ROV with the ability to rotate along all the X, Y, and Z axis, as well as crabbing (strafing) capabilities. The thrusters are encased in custom thruster guards that we created in Fusion 360 and 3D printed with ABS filament to perfectly fit the T100 thrusters. These specialized thruster guards are easily assembled, and provide solid protection for the thrusters, as well as preventing anyone from touching the moving blades and injuring themselves. A unique component of our thruster guards is that they guard both the front and backside of the thrusters. While many models of thruster guards only protect the front, or intake, of the thruster, our guards provide protection from both sides; this design is especially important when the thrusters are working in reverse.

Thruster Guards

The thruster guards (Figure 19) were originally designed in house using SolidWorks. However, they were recreated in Fusion 360 and 3D printed using extra durable ABS filament. The thruster guards are a compilation of many years of small adjustments and improvements on fitment and water flow. The guards prevent obstruction to the thrusters in multidirectional movement and provide safety for the pool retrieval team.

Figure 19: Thruster and Deconstructed Thruster Guards

Handles

After practicing in the pool, a great need for handles was recognized by the design team. In Fusion 360, the design team created handles (Figure 16) that would help in transporting Seawolf X and provide for a tether strain relief located on the rear handle. The handles were made by the 3D printer and are composed of ABS and reinforced by aluminum.

Camera

Seawolf X contains two standard definition CCTV style 1.2mm cameras (Figure 17), one located in the front of the ROV and the other in the rear, each in its own acrylic tube. This gives each camera plenty of room for a full range of motion. Both cameras receive power from the power control board. Live video footage is converted by an IP video encoder and is sent via ethernet in a CAT5e cable through the tether of the ROV to a router on the surface. As the surface controls are powered on, the video decoder connects to the ROV's video encoder board via the Ethernet communications link. This signal is then displayed on the TV. Having two cameras allows the pilot increased degree of visibility while attempting to maneuver the ROV in compact spaces and through debris. The cameras are attached to a servo that allows the pilot to rotate them 180 degrees along the x-axis. This allows the pilot to clearly view the surroundings and greatly minimizes blind spots.

Feet

Last year, the S.U.R.E. company went with a cylindrical foot design. S.U.R.E. designed simple feet in SolidWorks that feature a partially hollow design, allowing a single screw to be drilled up through the middle and securing each foot to the ROV. Initially, the foot had an opening in the bottom that could potentially retain air when the ROV is submerged. However, the 2021 team solved this by putting a few holes through the design to let any air escape. This design was easy for the S.U.R.E. company to 3D print due to its simplicity and printing replacements were cost and time effective. Due to the loss of one of the feet, the 2022 design team created on Fusion 360 a foot design that would solve the problems, navigated in the previous model. The current feet (Figure 18) are u-shaped with a hexagonal honeycomb insertion within the frame to allow support. This design is beneficial because the honeycomb has a hydrodynamic property that prevents drag and retention of water. The dimensions of the foot are 6 cm tall and 6.35 cm wide. The height is perfect for the clearance of the manipulator.

Software and Flowchart

At the heart of the control system is a Microsoft Windows 7 laptop running National Instrument's LabVIEW 2017. LabVIEW's Graphical User Interface (GUI) is straightforward and allows commands to be easily employed but is still complex enough to handle the control inputs of our electronic systems. LabVIEW allows the laptop computer to conduct the bulk of data processing, which is preferable to putting the stress on the onboard ROV microcontroller. The LabVIEW software controls our thrusters, cameras, tooling, and the manipulator via an XBOX controller. The Razr IMU (inertial measurement unit) provides ROV positioning feedback to pilot via a horizon indicator in LabVIEW. This IMU includes a triple-axis gyro, a triple-axis accelerometer, and a triple-axis magnetometer.

Other indicators and controls found in the LabVIEW GUI are thruster power output settings, which allow for finely tuned movements, temperature monitoring of the electronic environment, a depth gauge, actuator controls, and speed controls for the tooling. Additionally, there is an auto hover function which uses the pressure sensor. The sensor is a Blue Robotics Bar30 which can measure up to 300 m and has a depth measurement resolution of 2 mm. This allows for a highly accurate auto depth management.

Based on input from the XBOX controller (Figure 20) and the GUI, LabVIEW determines what action the ROV needs to perform. LabVIEW then issues commands via the tether to the ROV's on-board microcontroller ChipKit Max 32. The Max32 then responds accordingly by directing all of the ROV's components to complete the necessary action.

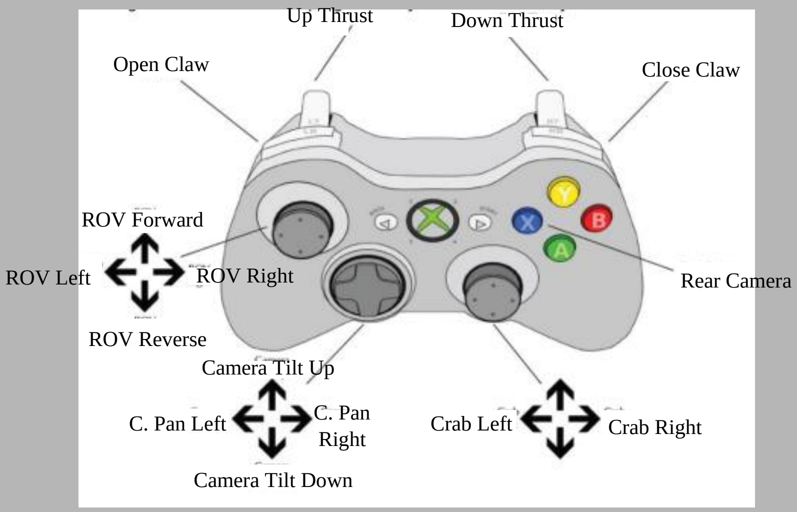
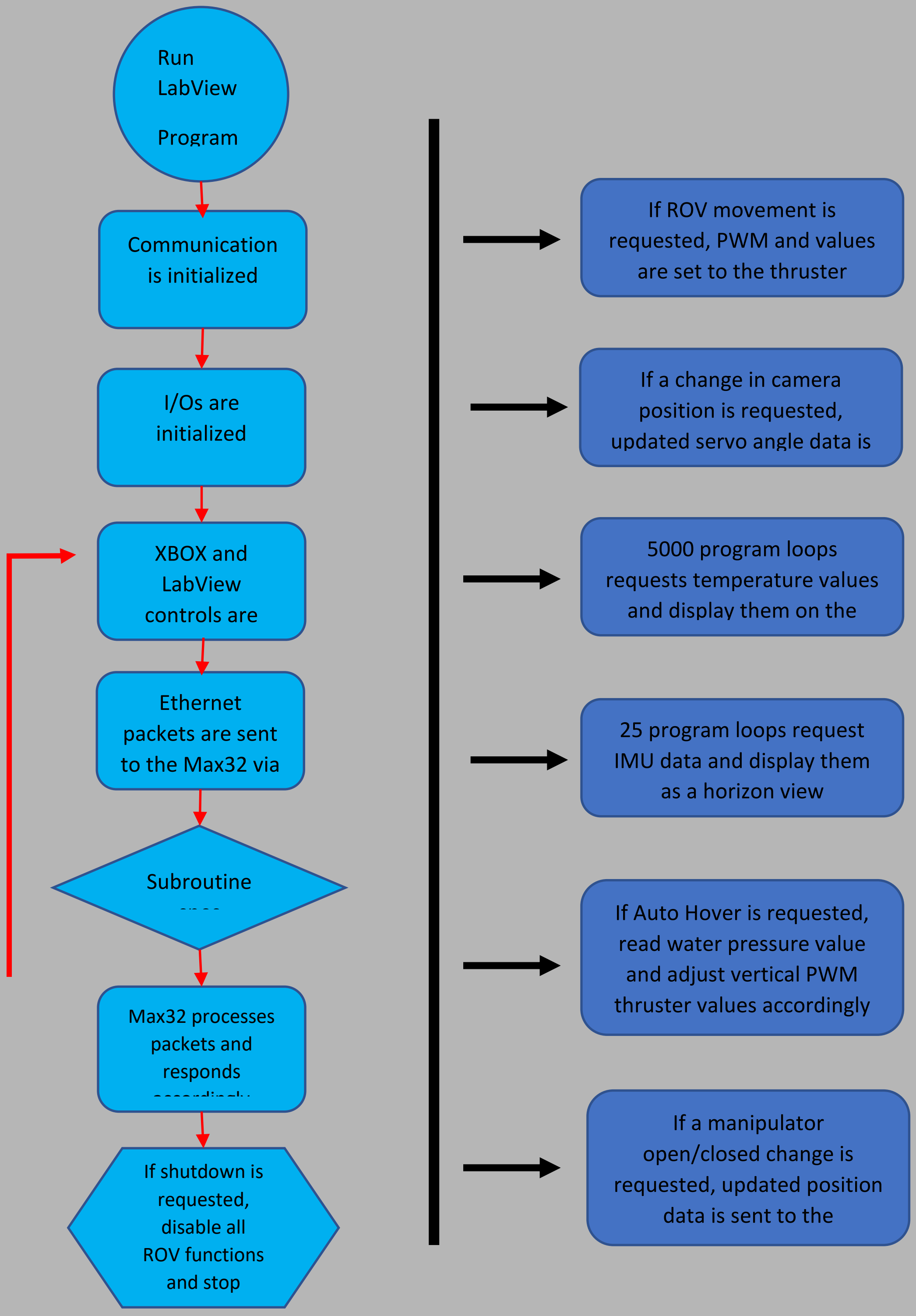


Figure 20: XBOX Controller and Actions


Run LabView Program
Communication is initialized
I/Os are initialized
XBOX and LabView controls are
Ethernet packets are sent to the Max32 via
Subroutine
Max32 processes packets and responds
If shutdown is requested, disable all ROV functions and stop
If ROV movement is requested, PWM and values are set to the thruster
If a change in camera position is requested, updated servo angle data is
5000 program loops requests temperature values and display them on the
25 program loops request IMU data and display them as a horizon view
If Auto Hover is requested, read water pressure value and adjust vertical PWM thruster values accordingly
If a manipulator open/closed change is requested, updated position data is sent to the

Preparation

Testing

Though most of Seawolf X's components were based on Seawolf IV, no corners were cut in confirming that everything worked collectively. The S.U.R.E team put Seawolf X through strenuous testing to ensure the quality of its product.

The first test in water was done in a large vat. The team used the vat to test the buoyancy of the vehicle as well as thruster capability and waterproof seals. After the ROV was determined fit for deeper water, it was taken to a local pool and tested to a depth of 3m. During this time, the company perfected the set up and take down of Seawolf X, learning how to work together seamlessly while the ROV was in operation. The team created a safety checklist as they worked through complications to ensure a safe ROV mission each time. This is when S.U.R.E. realized a need for a smoother and more practical way to carry Seawolf X.

Challenges

After the second test run in the pool, we discovered a flaw in the sealing of the acrylic window. The sealant did not form an adequate bond with HDPE encasement. This resulted in water entering the compartment housing the electronics (Figure 21) and ultimately damaging the power board. The power board needed to be totally replaced, with only a few components salvaged.

HDPE is an inert substance which is difficult to paint or apply adhesives to. Fortunately, we found a specific type of epoxy that bonds to HDPE and acrylic. This adhesive was Scotch-Weld DP 8005. To solve the problem with the acrylic, the design team put ridges in the acrylic and the HDPE frame; this allowed more surface area for the adhesive to bond. Washers were added to the stainless steel 6/32 screws with 1.905 cm threading so that they could grip the holes in the HDPE encasements which improved the watertight seal with the aluminum base.

A less technical challenge reared at the end of the school year when members acquired jobs. It was harder to coordinate meeting that successfully encompassed the whole team. New members outside of tech fields were introduced to the company putting the burden of explanations of team goals and operations on the employees.

Mission Planning

S.U.R.E. has a team solely dedicated to prop making and production. This ensures that props are made based on regulation and likeness to real obstacles when operating in the ocean. When deciding if more tools were needed to complete the missions, the team decided that the pilot was experienced and confident enough in the ability to complete tasks and had ample time to practice with props rather than add any additional tools. Props had to be taken to and from a local pool. The various capabilities of the Seawolf X means that a complicated setup process is required to prepare the ROV for full functionality, and practicing this setup is just as important as any other aspect of creating, preparing, and operating the Seawolf X.

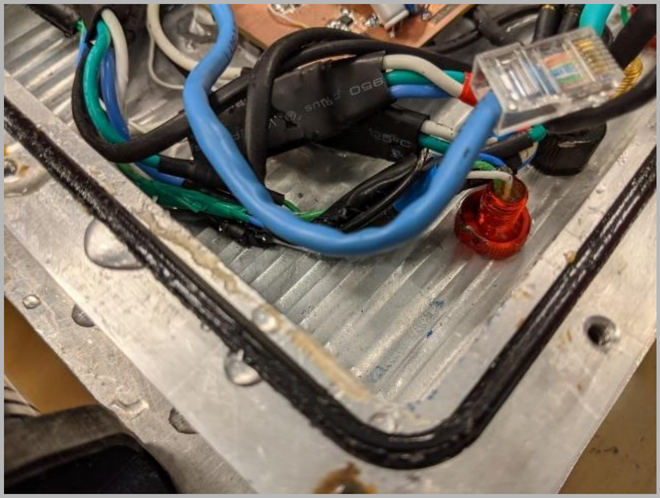


Figure 21: Water in Seawolf X

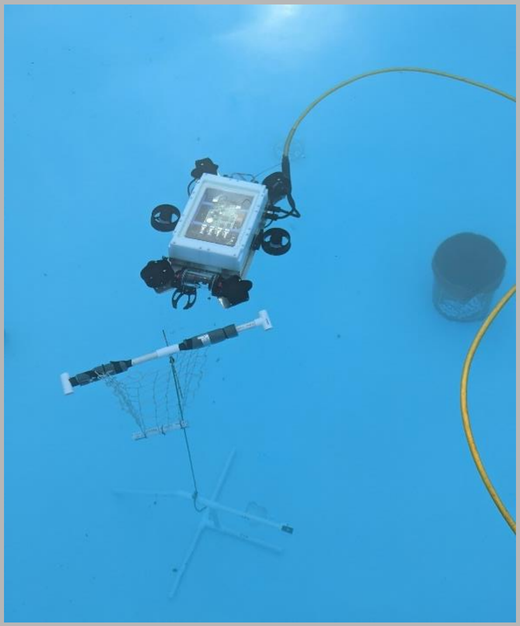


Figure 22: Seawolf X Executing Practice Missions

Buoyancy

Last year, the team had two options when considering the Seawolf IX's buoyancy: they could program the thrusters to a constant hover or add extra materials to the ROV using precise buoyancy calculations to make it neutrally buoyant. Ultimately, S.U.R.E. decided that calculating neutral buoyancy would be much simpler, energy efficient, and less prone to malfunction. Making the Seawolf IX neutrally buoyant involves finding the ROVs volume and comparing it to its weight. Even with these calculations, the 2021 team had problems with buoyancy, so the team added high-density marine foam atop Seawolf IX which allowed the ROV to be slightly buoyant in fresh water. Seawolf X was designed with this problem in mind. The 2022 team added space in the top lid of the ROV (Figure 23), which increased the volume of Seawolf X. With this greater volume, more water would be displaced due to the enlargement of the surface area, adding to the buoyant force without a substantial change to the mass. Weights can also be added to the corners of the ROV opposite the manipulator during competition to even out weight distribution and trim the ROV's buoyancy.

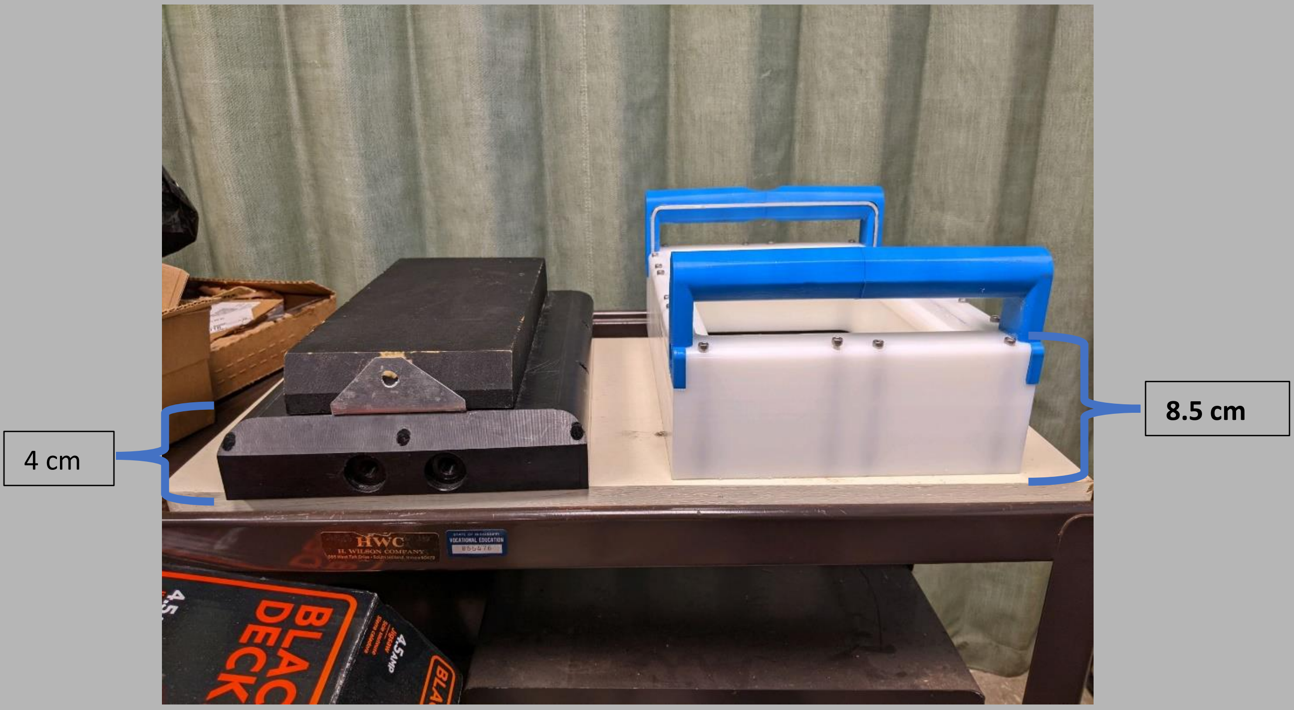


Figure 23: Seawolf IX Lid VS Seawolf X Lid

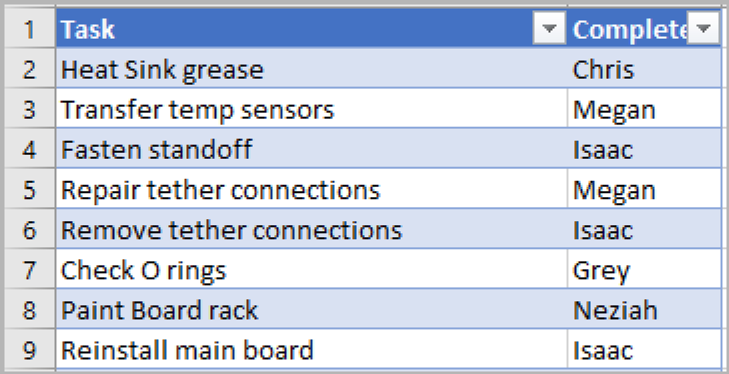
Logistics

Project Management

S.U.R.E Robotics organized a schedule for the company at the first of the year. This schedule included deadlines, meeting times, and other company events. At least once a week, usually on Fridays, the team met to discuss progress, future plans, and improvements to be made. These meetings were immediately followed by team working sessions. Additional working sessions were held throughout each week to continue the creation of Seawolf X. If additional meetings were needed, the team worked together to plan a place and time for them. The schedule was written on a board in the meeting room where all members could see it clearly and refer to it easily.

The creation of the ROV happened in three phases: design, manufacturing, and assembly. During the first phase, the company began to develop a plan for building the robot. A schedule and budget were created and S.U.R.E. decided on what materials to use for the new ROV, keeping in mind the conditions and tasks the robot would encounter as it performed the missions required of it. With these aspects in mind, the team decided to keep the same compact and sleek design of Seawolf IX, as well as many of the same main components, while making a few minor changes for improvement in accessibility and versatility. These changes were made using Fusion 360 instead of the SolidWorks program used in the production of Seawolf IX. After the initial design process, the electrical team used the blueprints of the ROV as a guide while creating the new circuit boards.

A progress report was taken midway through production. This report consisted of clarification of team position and a title for each employee. This allowed them to state what their role required and what progress they have made toward that role in the process of working on the ROV. A summary list (Figure 24) was created near the end of the project to guarantee that all smaller details were completed properly.



1	Task	Complete
2	Heat Sink grease	Chris
3	Transfer temp sensors	Megan
4	Fasten standoff	Isaac
5	Repair tether connections	Megan
6	Remove tether connections	Isaac
7	Check O rings	Grey
8	Paint Board rack	Neziah
9	Reinstall main board	Isaac

Figure 24: Part of Summary List

Budget and Expenditures

S.U.R.E company worked with a starting budget of 15,700 dollars due to the roll-over of the previous year's funds and the anonymous donation of 10,000 dollars. S.U.R.E was very meticulous regarding expenditures. After the first design meetings the team knew they wanted to keep the style of Seawolf IV. Once the design team communicated what components were going to reused and what was going to be bought, a budget was rendered for Seawolf X. This budget prepared for materials, travel, and food were based according to previous year's expenses and was essential to the success of this project.

Competition travels would be the largest expense for which the company had to allocate given the mode of transport would be flying unlike recent years. Food and shirts were very important for the budget because the money would be an investment into the energy and morale of the employees while practicing and competing. Overall, the S.U.R.E.'s budgeting and frugal spending efforts were a success with the company coming under target.

S.U.R.E. ACCOUNTING

Funding		Expenditures:	Budgeted	Actual
Starting Budget	5,700.00	Flights to LAX	$8,500.00	$7,000.00
Anonymous Donation	10,000.00	Truck/Van Rental ($100/day ea. for 7 days)	$700.00	$700.00
		Shirts	$200.00	$200.00
		Hotel Rental: (3 rooms x 6 days/nights)	$3,600.00	$3,600.00
		Electronics	$500.00	$625.00
		HDPE	$400.00	$320.00
		Food/Meals	$1,000.00	$200.00*
	$15,700.00		$14,900.00	$12,645.00
			* ependiture to-date	

Figure 25: S.U.R.E. Accounting

Conclusion

Future Improvements

S.U.R.E. is a great company to work within. What it lacks in funding and resources, it justifies in ingenuity and resourcefulness. Even so, S.U.R.E. can improve logistically and professionally. More effort can be invested into the recruitment of company employees at the beginning of the design process, which would allow all members to be at the same place in understanding the team's goal. Progress and improvements for the ROV should become a more important topic of discussion and understanding for future teams during weekly meetings. S.U.R.E. could also improve the integration of including non-technical majors into the internal working of the ROV.

Community Outreach

S.U.R.E. has a unique place within the community. Given that S.U.R.E. is based at a community college, interactions are much closer to the community. S.U.R.E. has a long history of outreach to young students who are the future of ROV production. In the past few years, the company has hosted ROV camps, provided interactive displays of ROVs, and appeared on radio stations to speak about the company and its mission to improve our water ways. This year, employees enjoyed refereeing high school robotics competitions. Students were able to witness S.U.R.E.'s love for robotics at a preview held on the school's Natchez campus for STEM Day. In the fall, the team traveled to the Children's Museum to host a robotics camp were the importance of improving the environment using ROVs was enforced.

Figure 26: Refereeing Competition

Figure 27: Students Working on Their Robot

Safety Standards

Throughout this project, safety has been a considerably important factor in the development of Seawolves X. At the beginning of the ROV development, all employees were briefed on how to work while maintaining their facilities. OSHA and MATE guidelines for safety in the workplace were followed. Employees' most pertinent PPE when working in the facility consisted of closed toe shoes, gloves, and goggles. Not only does S.U.R.E maintain an organized workspace but also company members who are trained in proper safety behaviors. The S.U.R.E. corporation ensures a safe and efficient working environment. In the event that an accident could not be prevented, first aid kits were of easy access to employees.

Safety features on Seawolf X include, but are not limited to, fuses and a tether relief. Fuses allow for regulation of excessive power to the ROV. The tether relief is located on the rear handle of Seawolf X and allows for a strain hold preventing connection detachment.

S.U.R.E's main objective is to uphold the nature of our water ways; Safety measures have been taken to make sure the ROV poses no risk factors to the environment.

S.U.R.E not only believes in ensuring safety in production, but also in operation. Operational safety is listed on the following page.

Safety Protocol

Operating Procedure:

1. Check that all company members are wearing safety glasses and close-toed shoes
2. Check work environment and ROV for any hazards (sharp edges, untidy cables, et/slippery area)
3. Check that power supply is off
4. Inspect electrical components and connections for water proofing
5. Connect surface computer to router
6. Connect coder to router
7. Connect tether to router
8. Connect tether to power supply
9. Connect tether to ROV

10.Connect power strip containing surface laptop, TV, router, power supply to external power supply

Initial Power Up:

1. Co-pilot powers on TV, router, and surface laptop
2. Co-pilot announces “power is on” as 48V power supply is turned on
3. Tether manager affirms electronic status lights are correct and alerts pilot and co-pilot
4. Launch team places ROV in water and keep it immobile
5. Launch team checks for leaks in the ROV (If leaking, refer to “Failed Leak Test”)

Launch:

1. Launch team releases ROV as copilot starts timer
2. Tether manager calls out “ready”
3. Pilot takes control of ROV and begins mission tasks
4. If communication with ROV is interrupted, refer to **Communication Issues”**

Retrieval:

1. Pilot steers ROV to pool side for launch team to retrieve.
2. Co-pilot calls “Ready to remove ROV”
“ROV is out of pool”
3. Launch team removes ROV from water and tether manager calls “ROV is out of pool”
4. Co-pilot stops timer

Shut down:

1. Co-pilot calls “shutting down” before powering off ROV.
2. Co-pilot shuts down surface laptop, router, TV and power supply
3. Tether manager disconnects tether from ROV.
4. Team packs all gear

Failed Leak Test:

1. Pilot brings ROV to pool side
2. Co-pilot calls “shutting down” and powers off ROV
3. Launch team retrieves ROV and begins troubleshooting
4. If problem is solved, begin process again with “Initial Power Up”

Communication Issues:

1. Co-pilot checks surface computer program for communication issues
2. Co-pilot checks serial connection to ROV
3. Co-Pilot checks if programs are running correctly
4. Pilot checks power supply
5. Tether manager checks tether for imperfections and connection

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