TECH REPORT

Co-Lin Seawolves

MATE 2024
Explorer Class

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SEAWOLF XI

Seawolf **U**nderwatering **R**obotics **E**ngineering
(S.U.R.E.)

Copiah-Lincoln Community College

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Introduction

Abstract

S.U.R.E. is a thirteen-person company with multiple years of designing, manufacturing, and operating robotic solutions to aquatic ecological problems. *Seawolf XI* is S.U.R.E.'s newest Remotely Operated Vehicle (ROV). *Seawolf XI* is designed to operate in a multitude of underwater environments. This ROV is fully equipped with tools to expand the Global Ocean Observing System, help protect and restore ecosystems and biodiversity, and assist with climate action.

Seawolf XI is a result of numerous and rigorous testing and design processes. With features like a modular frame, adaptable electronics, and an extensible software, *Seawolf XI* is designed to adapt to the ever-changing global environmental challenges. This technical document explains the *Seawolf XI*'s design and development processes, as well as how *Seawolf XI* will face the multitude of challenges and tasks it will face.

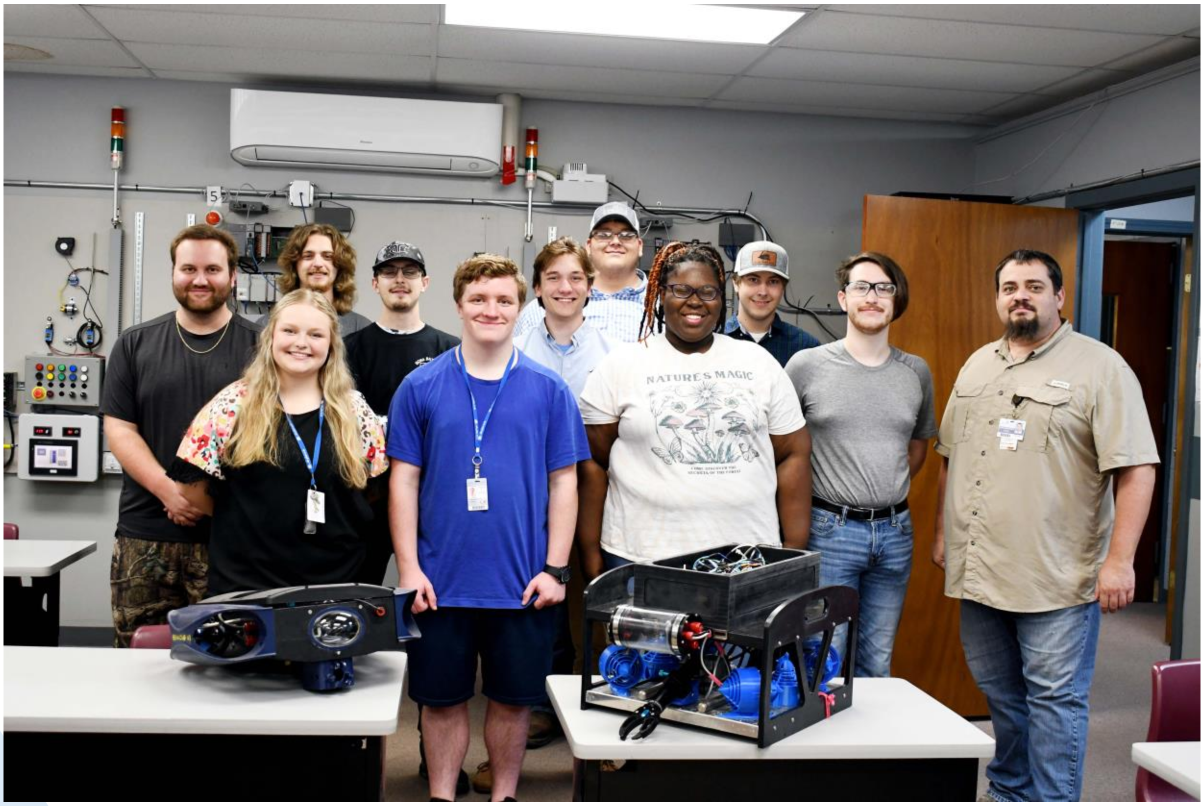


Figure 1: S.U.R.E. Team Members

Design Rationale

Modelling

Seawolf XI is S.U.R.E.'s newest ROV. The reuse of the core systems provided the opportunity for S.U.R.E. to re-design and manufacture *Seawolf XI*'s frame, electronics, and control software in a reasonable amount of time, allowing for a longer testing and troubleshooting period. We were able to recycle most of the materials used from the previous year's ROV, *Seawolf XI*, which provided a base for us to start with. S.U.R.E. has spent many hours working together to create and assemble *Seawolf XI*. The main aspects of the construction were design, machining, and assembly. Teamwork and diligence were essential during the creation and testing of the ROV. One of S.U.R.E.'s machining technicians manufactured a new main box (*Figure 2*). The rectangular design has a sleeker, more appealing appearance as well as better heat dissipation, and the main box is the most durable design we have created so far. The six thrusters on the *Seawolf XI* are vectored to provide the ROV with increased range of movement and planes of rotation.

A camera is mounted on the front of the high-density polyethylene frame, and a powerful manipulator is installed on the front of the base plate of the ROV. The *Seawolf XI* was primarily designed in SolidWorks, a CAD program with a near unlimited toolkit to allow full freedom when designing our ROV. The entirety of the ROV from the main body to the thrusters, and manipulator, was first modelled using these programs before physical construction began. Using this software allowed us to fully account for components needed to construction and assembly of the *Seawolf XI*, 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. SolidWorks has been a monumental tool in our journey to create efficient and streamlines drone designs for various uses.

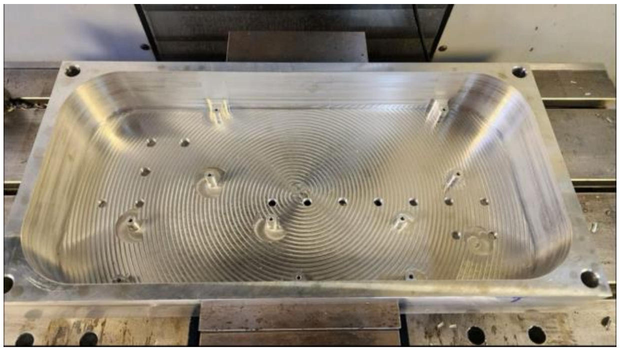


Figure 2: Aluminum main box

Design Rationale

Manufacturing Process

Our new main box was manufactured in-house (*Figure 3*). We used SolidWorks to design and model the new box prior to machining. The machinist used the in-house 3 Axis CNC machine to manufacture the aluminum main box.

S.U.R.E. decided to construct a new power supply circuit board (*Figure 4*). We used the software Kicab to design and model it before printing. We manufactured the Seawolf XI's new circuit board using a LPKF ProtoMat E44 PCB CNC mill. Having these in-house machines allow us to rapidly produce prototypes, which lessens the time spent manufacturing and testing.

Figure 3: Main Box Manufacturing Process

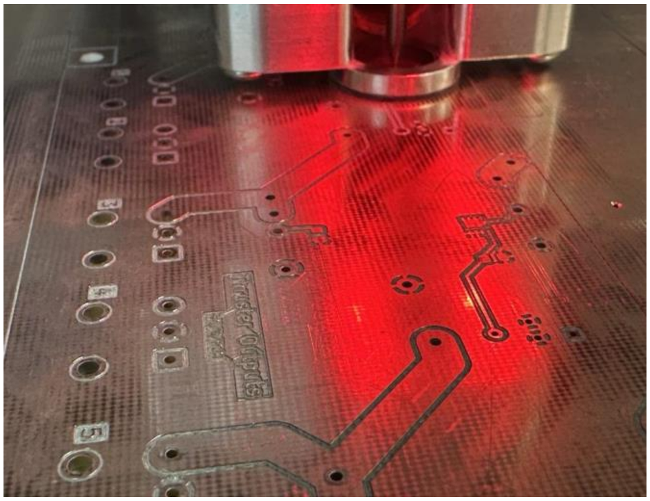


Figure 4: Circuit Board Manufacturing Process

Design Rationale

Troubleshooting and Testing Techniques

Initially, S.U.R.E. worked on several different manipulator tools that could assist in completing the various tasks assigned this year. Prototypical tooling design ideas included those resembling an extending claw grabber that would assist in collecting items from the sea floor. The claw design is based on a hardware tool created to pick up small, hard to grab items and hold them securely. Vacuum manipulators were also considered, capable of pulling debris into their grasp using suction. We ultimately found that simplicity of tooling design led to better performance on missions. Complex tooling can increase the chance of malfunction, so a basic manipulator purchased from Blue Robotics (*Figure 6*) along with adept piloting is more effective and efficient, and less to prone to failure or malfunction.

We originally had trouble with the Seawolf XI being too heavy, causing it to sink immediately once it was placed in the water. One of SURE's employees suggested some kind of foam to help with the buoyancy problem. We were able to use enough of the syntactic foam to keep the ROV from sinking as soon as it hits water. We then ran into the problem of it being too buoyant. We used different weights until the ROV was slightly positive while in the water (*Figure 5*), then attached those weights to the ROV.

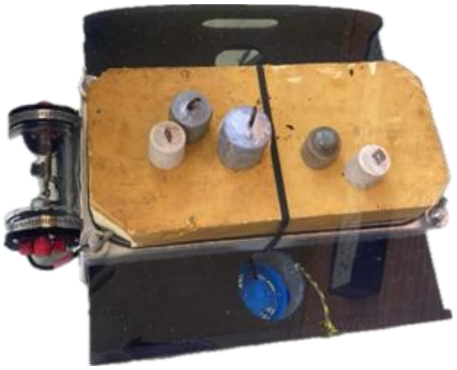


Figure 5: Seawolf XI during buoyancy trials.

Figure 6: Blue Robotics Manipulator

After multiple leak tests, we added the wires and the electronics. Once wiring was done, the Seawolf XI underwent numerous trials to ensure the functionality of each tool on the ROV. We tested each individual tool to guarantee there were no problems with the wiring and controls for each of the tools.

Mechanical Systems

Frame

The foundation of the Seawolf XI is the high-density polyethylene frame (HDPE). S.U.R.E. chose HDPE for the frame of the ROV for its marine resistant qualities. HDPE is noncorrosive, marine growth resistant, recyclable, durable, and shock absorbent, making it perfect for the *Seawolf XI*. Initially, the S.U.R.E. crew attempted to cut the base plate from the side of a washing machine, though this proved unsuccessful, as the washing machine sheeting was too thin to support the ROV. The aluminum was acquired from eBay and serves as the foundational cornerstone of the entire ROV. Aluminum was chosen for its resistance to corrosion due to oxidization, relative lightweight, affordability, and durability. Aluminum is also heat conductive, meaning it does not trap heat within the *Seawolf XI*'s main electrical box, and allows the water on the outside to cool the electronics and wiring on the inside.

Electronics Housing

The electronics are housed within an aluminum main box. The top half of the main box is made of acrylic and is removeable. A large custom fitting O-ring sits between the top and bottom half of the main box, along with two more slightly smaller O-rings. We put lubrication on all three O-rings to assist with sealing the lid, as well as providing additional waterproofing due to the lubrication's hydrophobic characteristics. We also put just enough lubrication on the tether attachments (*Figure 7*) to provide waterproofing.

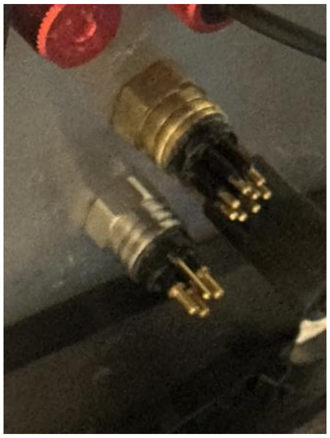


Figure 7: Tether Attachments.

Mechanical Systems

Thrusters

The *Seawolf XI* features six Blue Robotics T200 Thrusters (*Figure* 8) placed around the base plate of the ROV. The weight of the *Seawolf XI* combined with the powerful T200 thrusters makes this ROV the most powerful creation yet from the S.U.R.E. company. Two motors are run on an individual DC to DC converter. The motors run on 12V 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 the converter. The motor output is limited by software to decrease current draw to a total of 16A for all six thrusters. A power budget was calculated using P=48V*30A, providing the total power usage allowed for the robot. This helped the company decide that these motors could be effectively used. T200 thrusters use water as lubricant, which is cleaner and simpler than using grease. The thrusters' ability to propel in two directions gives the *Seawolf XI* total freedom to travel in any direction, which in turn provides the ROV the ability to rotate along X, Y, and Z axis, as well as crabbing capabilities. The thrusters are incased in custom thruster guards (*Figures 9 and 10*) that were created in SolidWorks and 3D printed with ASA filament to perfectly fit the T200 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. While many 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. A unique feature of these guards is they include a wolf head, which is the company logo.

Figure 8: Blue Robotics T200 thrusters.

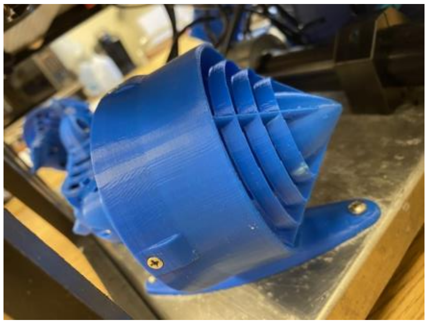


Figure 9: Back of the custom thruster guard.

Figure 10: Front of the custom thruster guard featuring a wolf head.

Mechanical Systems

Buoyancy

We decided to use syntactic foam to increase buoyancy on the *Seawolf XI*. Syntactic foam combines low density, strength, and buoyancy, making it a valuable choice for various underwater applications. We originally kept the foam as one big piece until we realized it was not evenly distributed throughout the ROV. We cut the large piece into four equal sections and attached them to the high-density polyethylene (HDPE) frame on the ROV (*Figure 11*). We added a few weights to the base plate of the ROV to slightly decrease the buoyancy level, and the foam and weights combined keep the ROV neutral while underwater.

Figure 11: Syntactic foam mounted on the Seawolf XI.

Electrical Systems

Electronics

The main board was assembled in house. It houses the main onboard microcontroller, an Arduino Mega2560. Other items found on this board are connections for four temperature sensors, two connections for servo outputs, connection for the Blue Robotics temperature/pressure sensor, lighting outputs, actuator controls, and an ambient temperature sensor. The power supply board (*Figures 12 through 14*) is a dual layer board that was designed and manufactured in house. This board sits beside the main board and is responsible for all voltage conversions. This board receives 48V from the tether where it is converted to the required voltages. There is a 5V and 12V DC to DC converter and three additional 12V DC to DC converters to power the thrusters located on this board. It also houses the outputs for each motor. These include a V-out (12V), GND (ground), and PWM (pulse width modulation). A 13-pin connection to the main board receives the PWM signals and passes them to the output pin for the motors. This connector also supplies control signals from the microcontroller to enable/disable the thruster DC to DC converters. Having the ability to power up or down the thruster voltage converters has several advantages. This allows the ROV to power on without the fear of the thrusters engaging before the microcontroller is ready. Once the ROV is powered on and communications is established, the pilot can then safely engage the thruster voltage converters. It also allows software to power down the thrusters in case of an overheating situation. See appendix page 23 for the SID (System Integration Diagram).

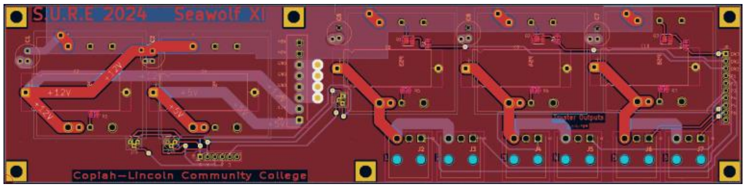


Figure 12: Seawolf XI's Circuit Board in KiCad

Figure 13: Top of Power Supply Board

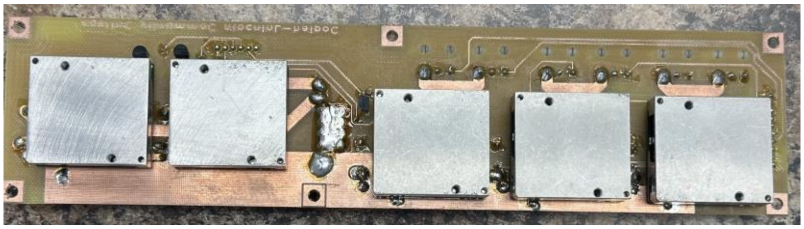


Figure 14: Underside of Power Supply Board

Electrical Systems

Tether

The Seawolf XI's tether (*Figure 15*) provides power, GND, and USB communications to the ROV via 8 and 3 pin Seacon bulkheads. There is a 30A in-line fuse within 30cm of the surface power supply. Both ends of the tether have strain relief provided by carabiners secured to Seawolf XI and the control station. The USB extender provides standard USB connectivity to all the main parts of the control system, including the laptop, microcontroller, and camera. The company uses an Outland's Technology tether, which is neutrally buoyant and durable enough to withstand strong currents and water pressure.

Figure 15: Seawolf XI's tether.

Submersible Connectors

Blue Robotics potted cable penetrators (*Figures 16 and 17*) are deployed to bring cables or wiring into and out of the electronics enclosure. They are sealed with epoxy and glue to prevent water from leaking into the electrical main box.

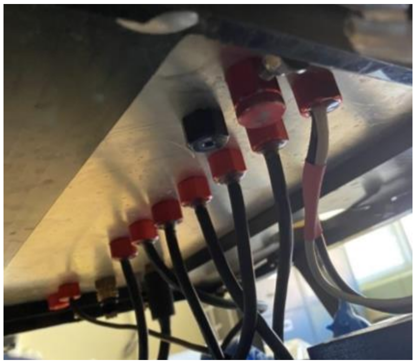


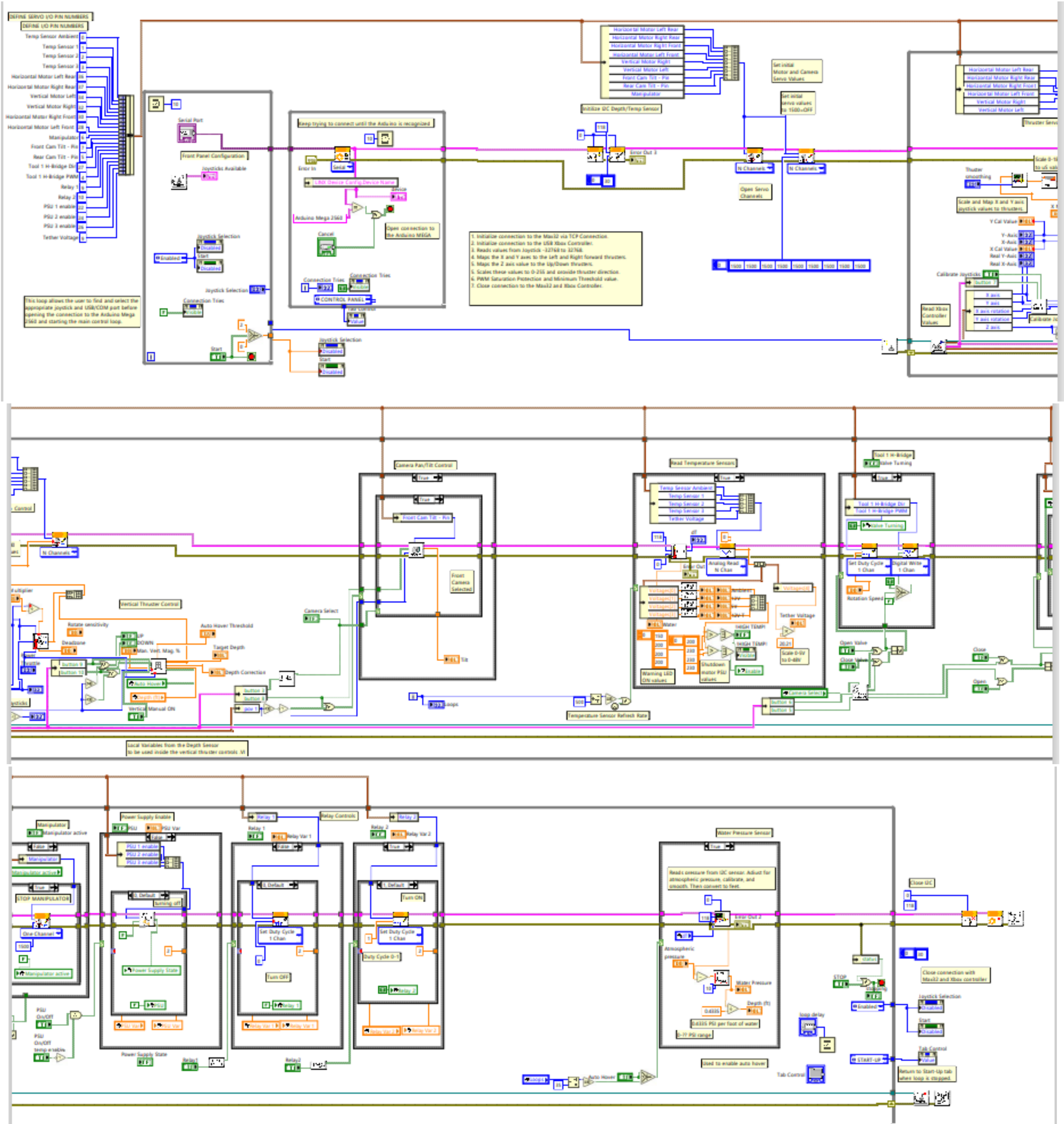
Figure 16: Wire Penetrators on Bottom of Electronics

Figure 17: Blue Robotics Potted Cable Penetrator

Software Systems

Software Infrastructure

At the heart of the control system is a Microsoft Windows 10 laptop running National Instrument’s LabVIEW 2021. LabVIEW allows the laptop computer to conduct the bulk of data processing (*Figure 18*) , which is preferable to putting the stress on the onboard ROV microcontroller. The LabVIEW software controls our thrusters, cameras, tooling, and manipulator via an XBOX controller. Indicators and controls found in the LabVIEW GUI are thruster power output settings, which allow for finely tunes movements, temperature meters, a depth gauge, actuator controls, and speed controls for the tooling. Additionally, there is an auto hover function using the pressure sensor. The sensor is a Bar02 which can measure up to 30 meters and has a depth measurement resolution of 2mm. this allows for a highly accurate auto depth management. See appendix page 21 for the Software Flowchart.



This loop allows the user to find and select the appropriate joystick and USB/COM port before opening the connection to the Arduino Mega 2560 and starting the main control loop.

1. Initialize connection to the Max32 via TCP Connection.
2. Initialize connection to the USB Xbox Controller.
3. Reads values from Joystick -32768 to 32768.
4. Maps the X and Y axes to the Left and Right forward thrusters.
5. Maps the Z axis value to the Up/Down thrusters.
5. Scales these values to 0-255 and provide thruster direction.
6. PWM Saturation Protection and Minimum Threshold value.
7. Close connection to the Max32 and Xbox Controller.

Reads pressure from I2C sensor. Adjust for atmospheric pressure, calibrate, and smooth. Then convert to feet.

Figure 18: LabVIEW Block Diagram

Software Systems

Pilot Interface

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. Based on input from the XBOX controller (*Figure 19*) and the GUI (*Figure 20*), LabVIEW determines what action the ROV needs to perform. LabVIEW then issues commands via the tether to the ROV's on-board microcontroller Arduino Mega 2560. The Arduino then responds accordingly by directing all the ROV's components to complete the necessary action.

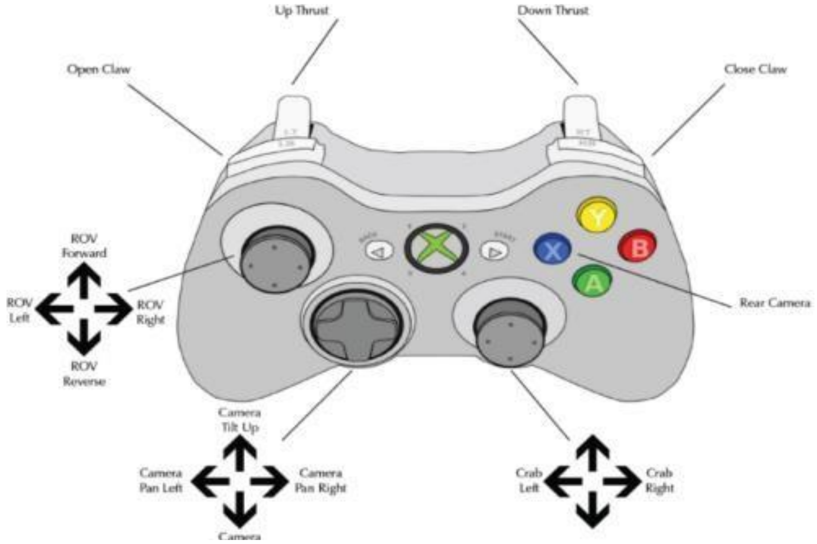


Figure 19: XBOX Controller Layout

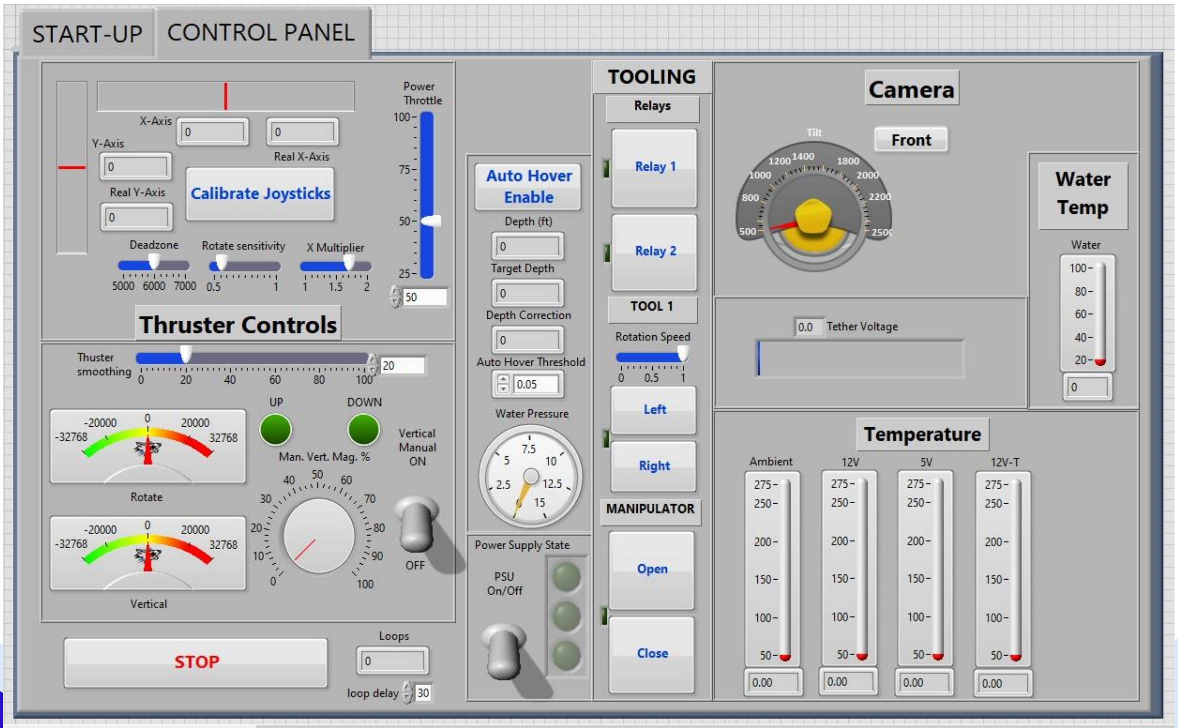


Figure 20: LabVIEW Pilot Interface

Tools

Gripper

The most prominent tool the *Seawolf XI* is equipped with is the Blue Robotics Newton Subsea gripper. The gripper opens to a 2.44-inch diameter and is pressure tested at depths of up to 984 feet. The S.U.R.E. company decided to keep the simple manipulator only, and instead practice on mastery of the controlling of this tool to complete missions effectively. The gripper (*Figure 21*) is placed at the front of the *Seawolf XI*, slightly to the left and under the camera. Placement close to the camera is especially beneficial during missions because having the manipulator within the camera's field of view assists in spatial awareness for the driver. This makes it much easier for the driver to see what he or she is doing with the manipulator. This manipulator is simple and user-friendly and is the main tool that will be used in most missions due to its versatility.

Figure 21: Subsea Blue Robotics Gripper

Rotational Tool

The Frictionally Assisted Rotating Tool (F.A.R.T. 3.0) (*Figure 22*) serves as a valve turning tool and utilizes a 12V DC Motor with a custom slotted handle attachment. In its third iteration, it has been modified to be more suitable to control water flow to probiotic irrigation systems in the Red Sea.

Figure 22: F.A.R.T. 3.0

Tools

Depth Hold

The *Seawolf XI* is equipped with the Blue Robotics Bar02 depth/pressure sensor (*Figure 23)*. The depth/pressure sensor uses the pressure from the water to control depth by deploying the vertical thrusters.

Figure 23: Blue Robotics Bar02 Depth/Pressure Sensor

Vision Systems

Seawolf XI contains one standard definition USB style 1.2mm camera (*Figure 24*), located on the front of the ROV in a dedicated acrylic tube. This gives the camera plenty of room for a full range of motion. The camera receives power from the power control board. Live video footage is sent through the tether of the ROV to the surface laptop, allowing the pilot to have visibility. The live video feed is displayed on the laptops secondary monitor. The camera being on the front allows the pilot increased visibility as he/she attempts to maneuver the ROV in compact spaces and around the coral. The camera is attached to a servo that allows the pilot to rotate them 180 degrees along the x-axis. This allows the pilot to clearly view his/her surroundings and greatly minimizes blind spots.

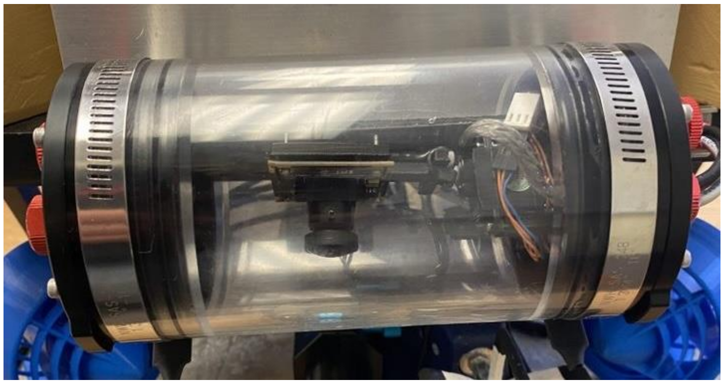


Figure 24:USB Camera

Safety

Company Safety Measures

At Seawolves Underwater Robotics Engineering (S.U.R.E.), safety standards, protocols, and procedures are of the utmost importance. Each member of the SURE company is expected to uphold the necessary safety standards to ensure a smooth, safe, and successful engineering process. (S.U.R.E. participates in OSHA safety briefings on slips, trips, and falls before beginning the construction of a new Seawolf drone model to make sure each company member is properly prepared to prevent accidents in the workplace, as well as how to handle such accidents in their unfortunate occurrence). One of the most important factors of maintaining a safe work environment is ensuring that S.U.R.E. workplace remains clean, organized, and tidy; something that SURE takes very seriously.

Vehicle Safety Features

From the start of the design process, the *Seawolf XI* was designed with safety and aesthetics in mind. All parts have been either CNC milled or 3D printed. Each part has been inspected for sharp edges that could either harm personnel or damage equipment/elements of the port that the ROV may encounter. A safety feature of the Seawolf XI includes the thruster guards covering the external thrusters. The guards on the sides of the ROV are 3D printed ABS plastic and protect the exterior mounted thrusters, deflect foreign debris found in port waters that could cause damage, and prevent injuries to handlers of the robot. The handles on the frame of the ROV provide a stable point to take hold of when transporting the *Seawolf XI* (*Figure 25*). The frame extends down to provide a landing surface that is stable, as well as providing protection to the base plate and tooling.

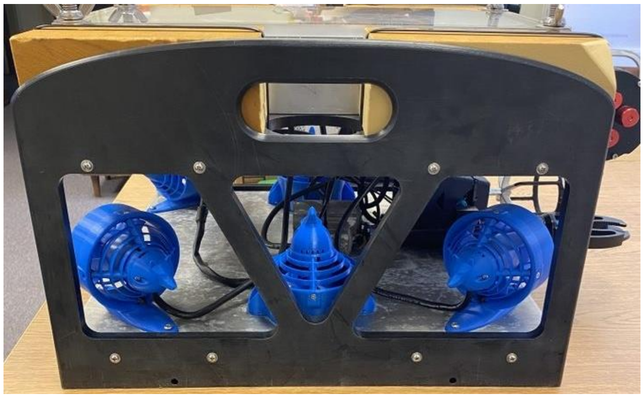


Figure 25: Side View of ROV

Safety

Operational Safety

Members of the company underwent safety training, including an electrical safety meeting. This meeting reviewed proper safety techniques when working with electrical components. Being cautious when working over circuits and live wires, wearing proper personal protective equipment, and being sure that electrical components are powered off before beginning work are a few of the ways that the company ensures member safety. During practices, we require the member removing the ROV from the water to call out various statements such as “Hands in” or “Hands on,” signaling to the pilot that we have a member with a hand in the pool and to proceed with extreme caution.

Checklists

See appendix page 22.

Lab Protocol

We require all members to wear closed-toe shoes and safety glasses while working in the lab to help prevent injuries. Loose clothing such as sleeves on jackets or shirts are not allowed, and we do not wear dangling jewelry. Members with shoulder length or longer hair are required to tie it back to reduce the risk of snagging or burning.

Teamwork

Collaborative Workspace

S.U.R.E has four sub-teams. These four teams are responsible for design, programming, electrical, and public relations, respectively. Company members are placed in each sub-team based on their experience and interests. Having mini teams within the company allows the members to focus and specialize on certain parts of the construction and documentation of the ROV.

Project Management

S.U.R.E Robotics created a schedule at the first of the year for the team to follow to make sure all deadlines were met well before their due dates. The schedule was written on a board in the meeting room where all members could see it clearly and refer to it easily. The team met twice a week for three hours throughout the 2023-2024 year, during which they designed, manufactured, and constructed *Seawolf XI*. The creation of the ROV happened in three phases: design, manufacturing, and assembly.

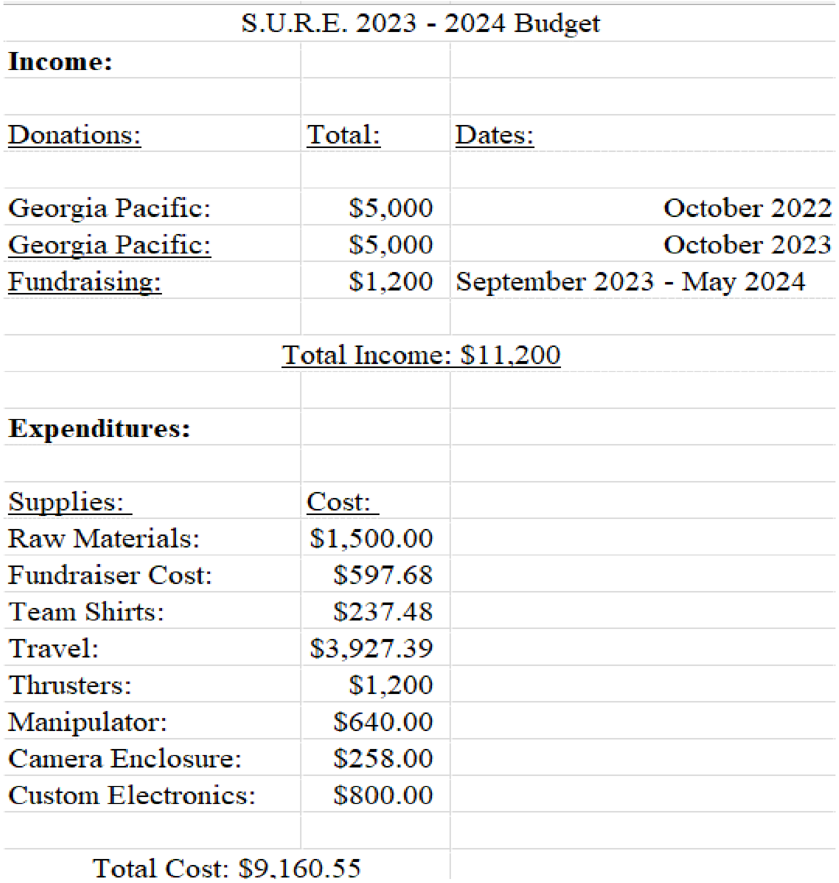
During the first phase the company began to brainstorm and plan. A schedule and budget were created and S.U.R.E. decided on what materials to use for the new ROV, keeping in mind the conditions and tasks the robot would encounter as it preformed the missions required of it. With these aspects in mind, the design team formulated a blueprint for the ROV and created a model using SolidWorks. Through much trial and error, they designed a compact and sleek ROV with the maneuverability and versatility to execute the tasks expected of it.

After the initial design process, the electrical team used the blueprints of the ROV as a guide while creating the circuit boards and other components. The programming team began to create the program needed for *Seawolf XI*, as well as the controller. The frame of *Seawolf XI* and the aluminum electronics housing were milled and the acrylic lid obtained.

The last phase of the construction of *Seawolf XI* was probably the most challenging. The programming, design, and electrical teams worked closely together, combining their work. After the frame was milled, the company assembled the ROV and began testing it. There were many

Teamwork

Finances



S.U.R.E. 2023 - 2024 Budget		
Income:		
Donations:	Total:	Dates:
Georgia Pacific:	$5,000	October 2022
Georgia Pacific:	$5,000	October 2023
Fundraising:	$1,200	September 2023 - May 2024
Total Income: $11,200		
Expenditures:		
Supplies:	Cost:	
Raw Materials:	$1,500.00	
Fundraiser Cost:	$597.68	
Team Shirts:	$237.48	
Travel:	$3,927.39	
Thrusters:	$1,200	
Manipulator:	$640.00	
Camera Enclosure:	$258.00	
Custom Electronics:	$800.00	
Total Cost: $9,160.55		

Figure 26: S.U.R.E. 2023 - 2024 Finances

Acknowledgements and References

- Georgia Pacific (Monticello) – donated $5,000.
- Brookhaven Country Club – use of their pool.
- Copiah-Lincoln Community College – use of their machines.
- Blue Robotics – tools used on the ROV.
- MATE ROV Competition – providing a safe space for students to come together and interact.

Conclusion

Challenges

We had a few challenges while building the *Seawolf XI*. Our first and most important challenge was making sure the acrylic lid did not leak while undergoing leak tests. Another challenge was testing for continuity of the control wires. We had a few disruptions, but they were easy fixes. Our most difficult challenge was getting the buoyancy of the ROV to slightly positive. The ROV itself has weight to it, so we added some syntactic foam to the HDPE frame. However, that made the buoyancy too positive, so we had to add weights. The hardest part of that was figuring out the exact amount of weight to add on the *Seawolf XI*.

Experiences

We had many experiences while building the *Seawolf XI*. The new members learned how to solder, connect wires safely, build props for the mission tasks, assemble the ROV, and pilot the ROV during practices. The S.U.R.E. company was able to expand their experiences and expertise while building and designing the *Seawolf XI*.

Future Improvements

A future improvement we hope to make is adding a rear camera. That rear camera would increase visibility and maneuverability for the pilot, as well as decreasing the chance of knocking a mission prop over or damaging the ROV due to running into objects.

Software Flowchart

Appendix: Software Flowchart

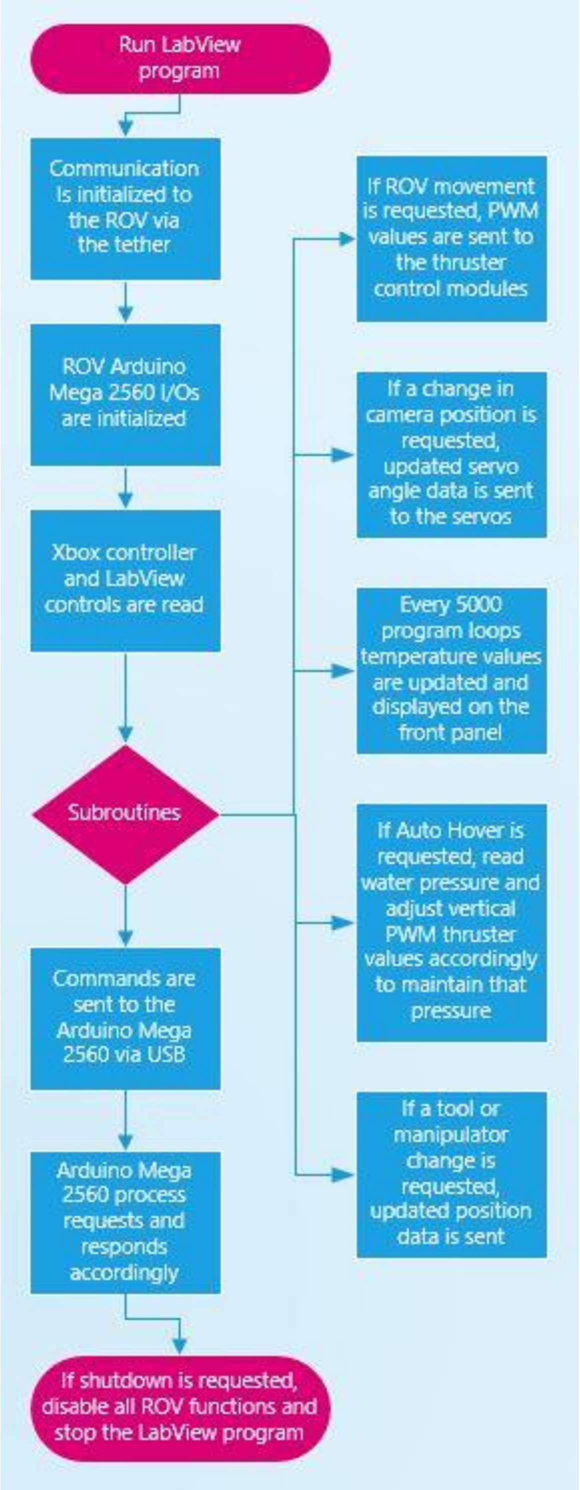


Figure 21: Seawolf XI's Software FlowchartFigure 27: Seawolf XI's Software Flowchart

Appendix: Company Safety Checklist

Set Up Procedure:

1. **Check that all company members are wearing safety glasses and appropriate shoes.**
2. **Check work environment and ROV for any hazards (sharp edges, untidy cables, wet/slippery areas)**
3. **Check that power supply is off.**
4. **Inspect electrical components and connections for damage.**
5. **Connect surface computer to USB extender.**
6. **Connect tether to USB extender.**
7. **Connect tether to power supply.**
8. **Connect tether to ROV.**
9. **Connect power strip containing surface laptop, secondary monitor, and power supply to wall plug.**

Initial Power Up:

1. **Co-Pilot powers surface laptop and secondary monitor.**
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. **Lauch team places ROV in water, keeping it immobile.**
5. **Lauch team checks for leaks in the ROV (if leaking, refer to "Failed Leak Test")**

Launch:

1. **Lauch team releases ROV as Co-Pilot 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."**
3. **Launch team removes ROV from water and tether manager calls "ROV is out of the 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, secondary monitor, and power supply.**
3. **Tether manager disconnects tether from ROV.**
4. **Team packs all gear.**

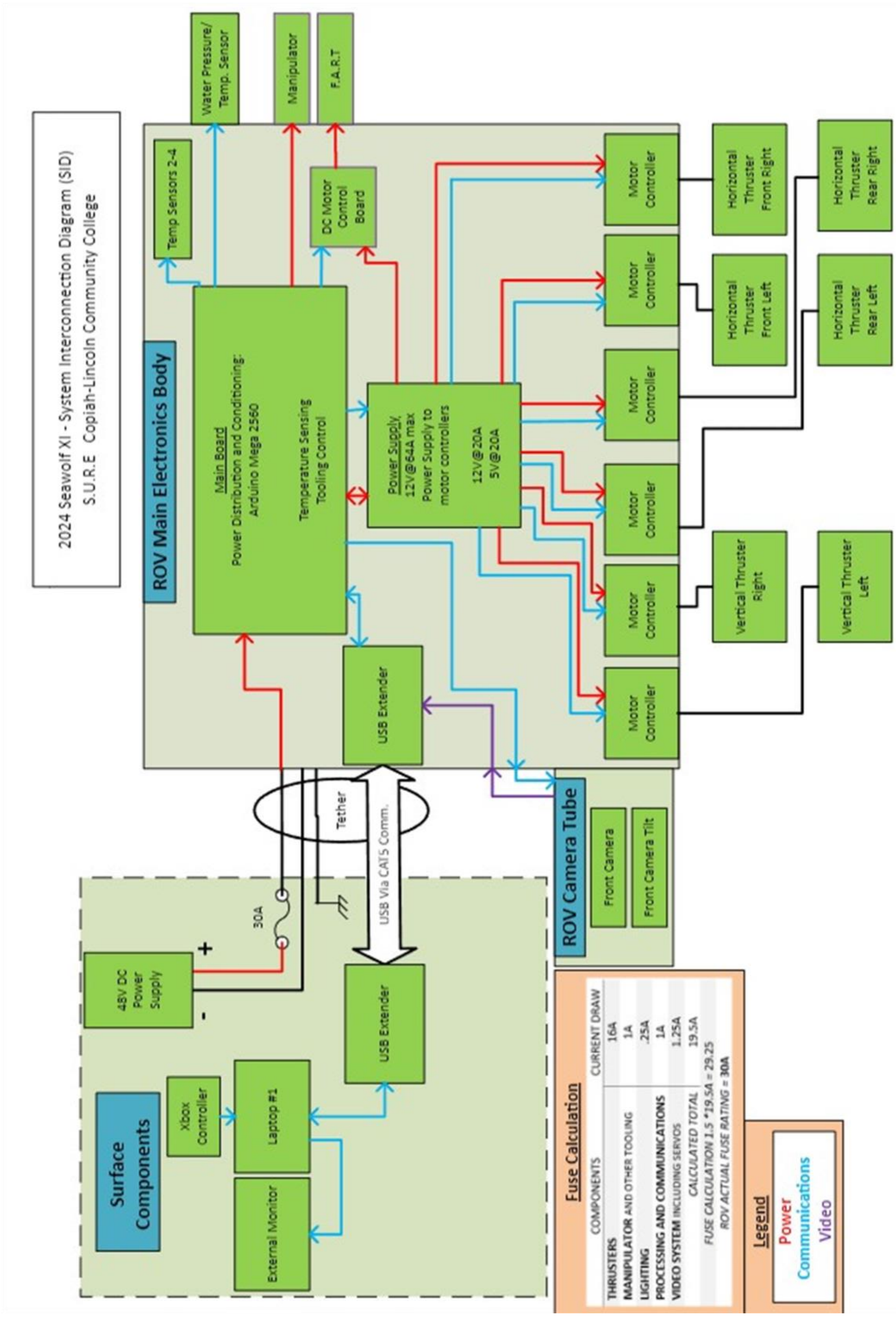
Failed Leak Test

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 tether connections to the USB extender.**
3. **Co-Pilot checks if programs are running correctly.**
4. **Pilot checks power supply**
5. **Tether manager checks tether connections and inspects for damage.**
6. **If a solution is not found, launch team retrieves ROV.**

Electronics SID



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

Figure 22: Seawolf XI Electronics SIDFigure 28: Seawolf XI Electronics SID