



MUREX ROBOTICS

>> MATE UNDERWATER ROBOTICS AT PHILLIPS EXETER
>> EXETER, NEW HAMPSHIRE, USA

// ATTEMPT THE IMPOSSIBLE.

TECHNICAL DOCUMENTATION

//MEMBERS

Crane Lee [CEO] (3rd Year/'27)
Fiona Liu [Mechanical Lead, Interim CEO] (2nd Year/'28)
Osbert Chang [Co-CTO] (3rd Year/'27)
Kevin Chen [Co-CTO] (1st Year/'28)
Sean Mahdavian [COO] (1st Year/'27)
Hopson Kounavis [CSO] (1st Year/'29)
Andrew Chen [Electrical Lead] (2nd Year/'28)
Oliver Choi [Software Lead] (1st Year/'29)
Shiloh Page [Electrical] (1st Year/'28)
Vincent Chen [Electrical] (1st Year/'29)
Devon Wilson [Mechanical] (1st Year/'29)

//MENTORS

Mr. Charles Mamolo [Robotics Coach and Mentor, Instructor of Science]
Ms. Julie LaFranzo [Robotics Coach and Mentor, Instructor of Science]
Ms. Courtney Shaw [Mentor, Instructor in Health Education]

CONTACT: Please email <first name of member>@mrx.ee for inquiries.
Example: crane@mrx.ee, or murex@mrx.ee for general inquires.

Photo: F. Liu
Render: F. Liu

TABLE OF CONTENTS

<u>MUREX ROBOTICS 2026</u>	1
ABSTRACT	3
TEAMWORK	4
>> Company Structure	4
>> Scheduling and Planning	4
>> Challenges	5
DESIGN RATIONALE	6
>> Innovations	6
>> Systems Approach	6
>> Vehicle Structure	7
VEHICLE SYSTEMS	8
>> Motion System	8
>> Control System	8
>> Vision System	8
>> Topside System	9
>> Strain Relief	9
CONTROL/ELECTRICAL SYSTEM	10
>> Carrier Board	11
>> Power Board	11
>> Ethernet Switch	12
>> ANYESC + ESC Carrier	12

SOFTWARE SYSTEMS	13
>> ArduPilot Tooling	13
>> MASCP	14
>> Lua Scripting	14
>> Component Test Scripts	14
>> Diagnostics Program	15
>> ANYESC Firmware	15
PROPULSION	15
BUOYANCY AND BALLAST	16
BUOYANCY MODULE	17
BUILD/BUY. NEW/USED.	17
CRITICAL ANALYSIS	18
>> Electrical R&D and Testing	19
PAYLOAD & TOOLS	20
SAFETY	21
>> Safety Rationale	21
>> Deployment Safety Checklist	22
>> Pre/Post Deployment Safety Protocol	22
SYSTEM INTEGRATION DIAGRAM	23
COST ACCOUNTING	24
>> Accounting	23
>> Budget	23
ACKNOWLEDGEMENTS & REFERENCES	24

OUR MISSION: “MUREX isn't just another high school robotics team. With a vision to revolutionize and democratize the underwater robotics industry, **we push technological boundaries and contribute to the community around us.** MUREX doesn't cut corners. MUREX doesn't settle for OK. We do it right.”
THINK DIFFERENT.
UNLEASH INNOVATION.
ATTEMPT THE IMPOSSIBLE.

CORE BELIEFS:

- “The time of youth is the important period, on the improvement or neglect of which depend the most weighty consequences, to individuals themselves and the community.”
- “Goodness without knowledge is weak and feeble, yet knowledge without goodness is dangerous, and that both united form the noblest character, and lay the surest foundation of usefulness to mankind.”
- “And it shall ever be equally open to youth of requisite qualifications from every quarter.”
- Most importantly, **NON SIBI** (not for oneself)
- **Phillips Exeter Academy Deed of Gift**, May 17th, 1781
 - Signed by John and Elizabeth Phillips

ABSTRACT

The MUREX (MATE Underwater Robotics at Exeter) Robotics Company of Phillips Exeter Academy (PEA) from Exeter, New Hampshire, USA developed the **MUREX ROV V5**, a lightweight, low-cost, and open-source ROV to meet the challenges described in the 2026 Marine Advanced Technology Education's (MATE) **Request for Proposals (RFPs)** and to address the needs of the global marine robotics community. Our team consists of 11 members with diverse skill sets in **mechanical, software, and electrical engineering**. MUREX strives to attempt the impossible in everything we do.

The MUREX ROV V5 and crew aim to: 1. **Collect data** and create models of ocean ecosystems, 2. Preserve marine biodiversity and **protect wildlife**, 3. **Prevent iceberg collisions** and environmental damage as sustainable offshore energy develops, and 4. Engineer a **vertical profiling float (mrxFLOAT)** as outlined in the MATE RFP. We have achieved this with **advanced control** software/electronics, **custom waterproofing**, two high-resolution cameras, and a versatile manipulator featuring **three** degrees of freedom.



Team Photo at Elizabeth Phillips Academy Center, Exeter, NH. Photo: C. Mamolo

// COMPANY PROFILE

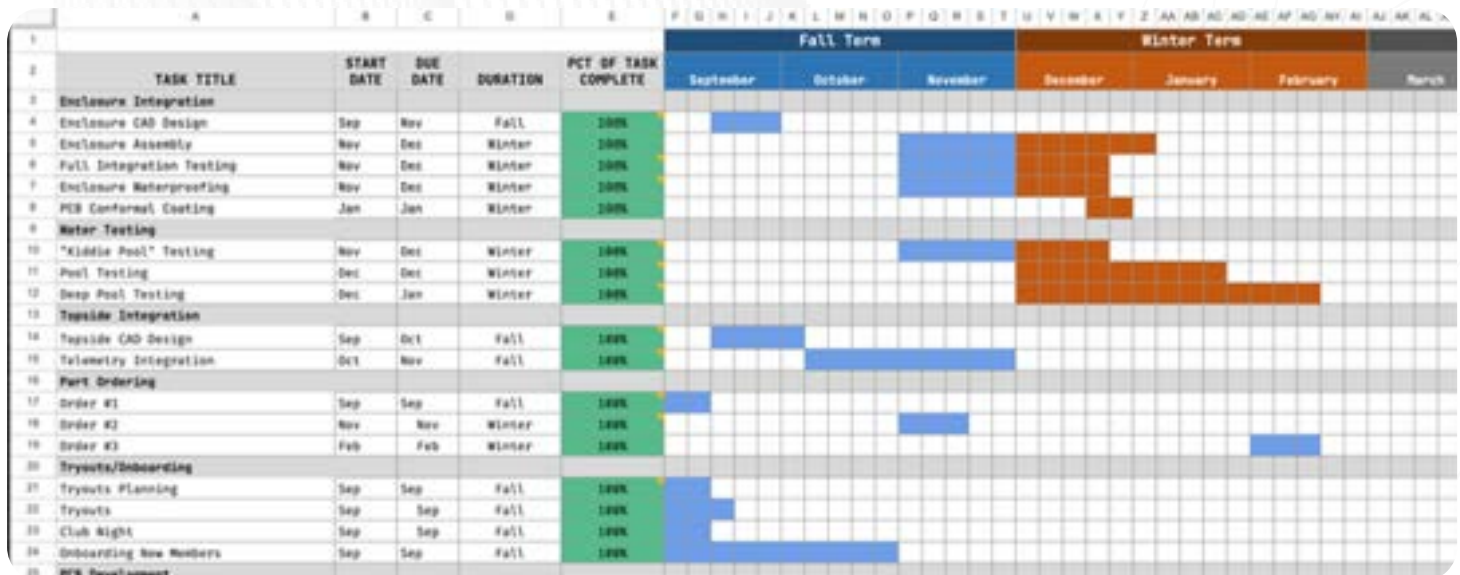
MUREX Robotics Company is composed of dedicated and creative high school students from diverse backgrounds. The strength in our dimensionality of thought makes MUREX a team of **astute problem solvers** who are able to combat difficulties with versatility and flexibility. The agile support of our experienced members creates a culture within our company that motivates all members to strive for the realization of MUREX's core values. **Innovation is our obsession**, though we are also aware of the importance of environmental and financial impacts. Our hard work in conjunction with our sound rationale makes MUREX a leading underwater robotics company and, ultimately, **a team of future inventors**. Our 11 members contribute to MUREX through our **3 subgroups [mechanical, software, and electrical]** with consistent communication and thorough attention to detail.

// SCHEDULING

As the MUREX Robotics Company is based in a boarding school, we are presented with unique challenges and advantages. Many of our members are international, residing in locations around the globe including **Shanghai, South Korea, Beijing, and Hong Kong**. The rest of the team resides in **7 different US states** from Texas to New York. Thus, meeting online over break always presents challenges. We make extensive use of **when2meet.com** to plan our remote and in-person meetings. As robotics is not a structured activity during the school day at our school, team members must find free time outside of their existing academic, athletic, and extracurricular commitments for MUREX. We also have a MUREX team **Discord server** where we manage all communications and discussions. We extensively utilize **Gantt charts** to schedule and plan, helping us reach team deadlines. Lastly, in each subgroup of MUREX (Mechanical, Electrical and Software), we assign tasks to different team members assuring to meet deadlines and top priorities with high efficiency.

// PERSONNEL

Crane Lee [CEO] (3rd Year/'27)
Fiona Liu [Mechanical Lead, Interim CEO] (2nd Year/'28)
Osbert Chang [Co-CTO] (3rd Year/'27)
Kevin Chen [Co-CTO] (1st Year/'28)
Sean Mahdavian [COO] (1st Year/'27)
Hopson Kounavis [CSO] (1st Year/'29)
Andrew Chen [Electrical Lead] (2nd Year/'28)
Oliver Choi [Software Lead] (1st Year/'29)
Shiloh Page [Electrical] (1st Year/'28)
Vincent Chen [Electrical] (1st Year/'29)
Devon Wilson [Mechanical] (1st Year/'29)



Gantt Chart. Photo: D. Wilson



// INNOVATIONS

Problem: Lack of low-cost, advanced electronics for underwater robotics

Solution: One of our biggest breakthroughs is the MUREX electrical system. *Our electrical engineering team works at the cutting edge of industrial, high-performance (HP) robotics.* We focus on making fully open-source electronics that undercut commercial offerings at 5-10% of the cost while being interoperable with existing options. (See Control/Electrical System)

MUREX is proud to have achieved the following:

- [Jun. 2024] World's smallest and lowest-cost Ethernet Switch, mrxSwitch v2.0. Placed #1 on Hacker News (~6/15/24) with +600 upvotes. Gained +1 million interactions with the website and +100 stars on GitHub in 24hrs. Published on Tom's Hardware, Techspot, ALL3DP, and other various industry platforms/magazines. Reported by various educational creators, reaching over 3 million views on YouTube and Instagram.
- [Nov. 2024] Open-sourced design and demonstration of a 25A ideal-diode protection board for ROVs, mrxShield
- [Dec. 2025] One of the highest data density (triple-channel power monitoring with an embedded controller) power modules, MUREX Smart Power Board
- [Oct. 2024] Ultra compact, 12A custom 5V DC-DC converter board
- [Jan. 2025] World's first open-source USB-modular and highest-power density sensorless field-oriented control ESC hardware design
- [Mar. 2025] Customized open-source BLHELI_S firmware configuration for a 4-1 ESC to drive underwater thrusters based on the BlueRobotics Basic ESC
- [Mar. 2024] World's first open-source CM4-based ROV control board, MUREX Carrier Board
- [Feb. 2026] mrxFLOAT open-source float design

ALL DEVELOPMENTS ARE OPEN-SOURCED ON GITHUB

- [Mar. 2024] World's first open-source implementation of a USB3.0, MUREX Carrier Board
- [Nov. 2023] World's first modular serial single ESC, MUREX ANYESC
- [Dec. 2023] One of the smallest open-source dual-output high power modules designed for 12V/5V/3.3V DC applications, MUREX Power Board
- [Dec. 2023] World's first open-source Ethernet Switch, mrxSwitch v1.0
- [Nov. 2023] Open demo of OFDM (orthogonal frequency division multiplexing) over galvanically isolated DC power lines, mrxPLC

// SYSTEMS APPROACH

MUREX designs the ROV's mechanical, software, and electrical systems in parallel. Subgroup leaders handle each respective system. Over the summer, the team convened to brainstorm ideas through research and discussion, as well as establish "concrete" systems. These include:

- Software infrastructure for the electrical team to design around
- Standardized electrical connectors between the PCBs
- Enclosure dimensions for the mechanical team to design around

This allowed our team to work asynchronously while assuring each component of the robot could be assembled and function as expected. This was a major improvement to our scheduling and planning in comparison to last year, where the software architecture relied on the completion of the electrical system, which relied on the mechanical requirements.

Each system was designed with **adaptability in mind**. The mechanical design offers maximum flexibility while providing a streamlined shape to minimize drag. The use of standard metric measurements across the robot ensured construction and modification were completed as expected.

The MUREX ROV V5 has a 45cm x 36cm x 20cm chassis constructed of 8 side panels and 3 bottom plates securely connected by 3D printed parts. These plates were CNC milled in-house from 0.635 cm **Self Reinforced Polypropylene plastic (SRPP)**. Two aluminum extrusions are utilized alongside T-nut fasteners to mount our claw. This modular design allows for **convenient mounting and assembly**.

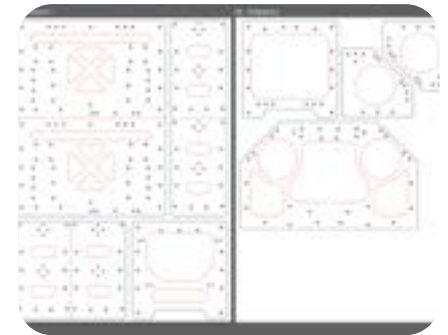
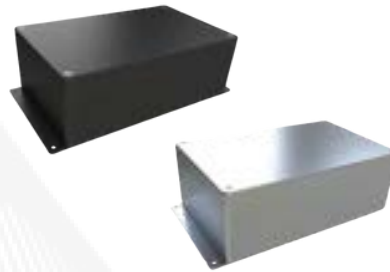
The octagonal frame design houses four vertical thrusters inside to prevent entanglement. The four horizontal thrusters are mounted at 45° angles outside the frame to reduce crowding and restriction of water flow. Our 8-thruster configuration allows for movement in **all six degrees of freedom**.

During the prototyping phase, MUREX successfully mimicked SRPP with inexpensive, laser-cut acrylic. Through this method we were able to **accurately test and perfect** the design.

Last year, we experienced frequent leakages with our rectangular polycarbonate enclosures, and decided the switch to **aluminum enclosures** for the following reasons (see bottom left).

Description	Cost Efficiency (max 10)	Construction Ease (max 5)	Benefits (max 20)	Concerns (min -10)	Total Score
Aluminum extrusion exoskeleton	+9	+5	High extensibility strength +7	ROV is limited by the extrusion's size and design -8	13
Marine-grade HDPE chassis	+5	+3	Very high strength +7 Streamlined design +10	Cannot easily modify design -3 HDPE is soft -5	17
3D printed design (PETG or PLA-CF)	+10	+2	Very high flexibility +5	Very low strength -10	7
SRPP plates	+6	+3	Very high strength +7 Ease of modification +10	Cannot make major changes to design -2	24 our chosen design!

AN-23F Aluminum Enclosure. Photo: Polycase



MUREX ROV Chassis Cuts. Photo: O. Chang

ENCLOSURE DESIGN MATRIX

Enclosure	Size (max 10)	Depth (max 20)	Advantages (max 20)	Concerns (min -20)	Total Score
Aluminum Enclosure	Large +8	High +19	Easy to design, mount, and repair +10	High cost -5 Not visibly inspectable -5	32 our chosen design!
Polycase Polycarbonate Enclosure	Large +8	Low (structural deficiencies beyond 50000 Pa) +12	Easy to design, mount, and repair +10, transparent top for viewing +5	Not optimal for underwater use, malleable, easy leaks -5	20
Blue Robotics Cylindrical Enclosure	Small +2	High +20	Can withstand depths, designed for ROV usage +10	High cost -10 difficult to repair and troubleshoot -5	17
Custom Enclosure	Flexible +10	Unknown +5	Flexible to match requirements +7	High risk of catastrophic failure -17	5

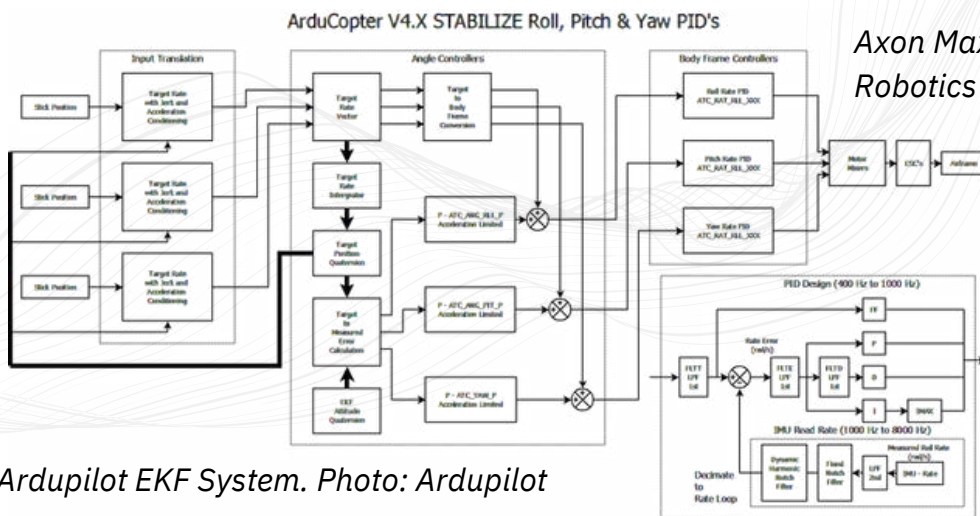


MUREX ROV Chassis Plate CNCing. Photo: O. Chang

VEHICLE SYSTEMS

CONTROL SYSTEM

The control system accurately controls the 8 thrusters and manipulator servos, allowing the demo team to make real-time observations about the mission. MUREX's tuned EKF (extended Kalman Filter) with **22 estimation states across our 10 DoF** sensing allows our robot to be fully stabilized along all axes of motion.



VISION SYSTEM

The vision system integrates USB front camera IP (internet protocol) back camera to stream live video to the topside. The MUREX Vision System includes a top-mounted, wide Insta360 link 2c camera from Insta360 and a lower, angled narrow FOV camera from Amcrest Technologies. The Insta360 camera is chosen for its **light in weight, excellent low-light performances and high video quality**. The IP camera were chosen for its **low cost, robust enclosures, and H.264 compression**.

Many existing vision system implementations use 2 USB cameras with multiplexing. However, that means only one camera can be displayed at a time. This is an inherent issue with video encoding on low-performance hardware, so MUREX bypasses the issue completely with the combination of IP and USB system. These concurrent camera views, provides the best clarity and lowest delay. The cameras have intersecting FOVs, minimizing parallax. We used a WP-31F clear polycase enclosure to house the Link2c camera on the front of the robot, while also using Molykote and penetrators to securely waterproof and be able to pressure test the enclosure for reliability. MUREX further enhanced the IP camera's existing waterproofing by applying Molykote 111 and O-rings to each screw entry. The Insta360 camera connects directly to the Raspberry Pi 4 and the Navigator Board. The Ethernet outputs of the IP camera connect to the MUREX Ethernet Switch.

MOTION SYSTEM

The motion system involves driving the 8 BLDC thrusters and controlling all servos. A major factor we considered this year was the complexity of existing ESC systems and their interoperability. The MUREX Motion System is designed with **universalization in mind**, allowing for rapid expansion and modification of the system with minimal downtime and modifications.



Axon Max Servo. Photo: Axon Robotics



T200 Thruster. Photo: Blue Robotics



Positioning of Thrusters. Photo: F. Liu



Amcrest Camera. Photo: Amcrest

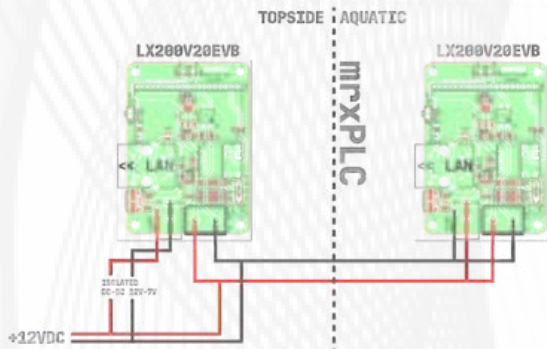


Insta 360 camera Photo: Insta360

//TOPSIDE SYSTEM



MUREX Topside. Photo: A. Bayraktar



mrxPLC Functional Diagram.

Diagram: M. Liu.

The MUREX Topside is built around a heavily modified **V700 Pelican Vault Case**. A 29" ultrawide monitor coupled with a 14" laptop monitor across the top of the case is run by an Apple M4 Mac Mini. All of the ROV power delivery systems including the LX200v30 are embedded into the bottom of the case. The demo team has access to all topside wiring through an easily removable PETG top layer. The suitcase has ample space to hold all the required electronics as well as tools and the controller. All connections into and out of the topside are strain-relieved. **The main DC input is passed to the robot through the tether connection and the mrxPLC system in parallel.** The topside uses USB-C to enable USB-C charging, USB device connection, and HDMI output to the monitor. A Pelican case was selected for its **durability, space, and ease of transport**. Previously used commercial suitcases proved unreliable, as rigidity was a constant issue for the previous topside build around an Amazon Basics suitcase. Upon completing a deployment, the demo team can efficiently prepare for departure by safely cutting power to the ROV, detaching from AC power and DC power, and closing the case with heavy duty clamps. The wheels on the case also allow for convenient transportation.

//TETHER DESIGN RATIONALE

The strain relief system on the back of the ROV uses metal wire as a medium **to take the 99.5% of the physical strain off the main tether**. The tether wires are friction clamped to four metal wire loops, which connect to the structural frame of the ROV through loops integrated into the SRPP frame. MUREX conducted multiple iterations of strain relieving, ultimately settling on this design for its simplicity and reliability. The distributed stress from using four metal wires allows the strain relief to be so robust that it supports the weight of the robot for extended periods of time.

The tether is highly flexible and experimentally modified with flotations to be neutrally buoyant. Our two tether managers are trained in constant communication to avoid entanglement. One manager stands closer to the ROV and provides between 6" to 12" of slack. The other keeps the excess tether organized by coiling it with the over-under method.



H. Kounavis manages tether. Photo: F. Liu



Strain Relief. Photo: F. Liu

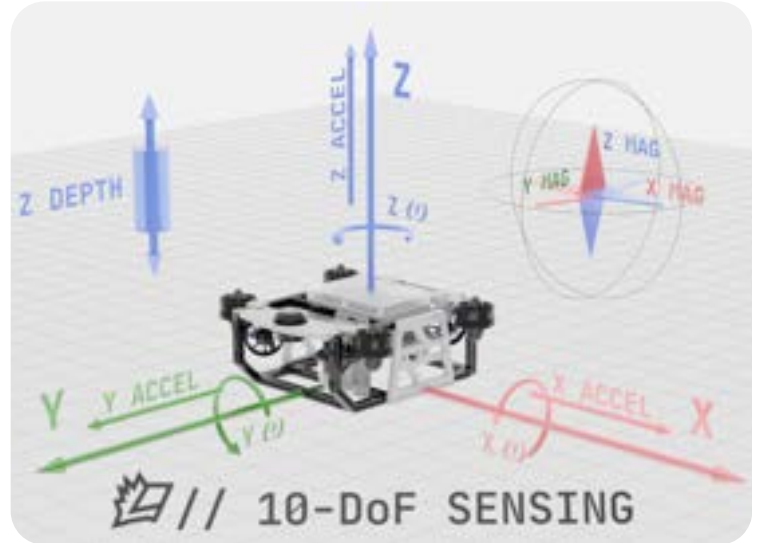
CONTROL/ELECTRICAL SYSTEM

> OVERVIEW

The MUREX Aquatic Electrical System is an **advanced, open-source design offering 10-DoF sensing, input power, transient protection** on every major connection, and various innovative PCBs. The MUREX ROV V5 system utilizes a custom Linux distribution, mrxOS, a custom control software built on top of Ardupilot, mrx, and many custom software systems such as MASCP (MUREX Asynchronous Serial Communication Protocol) and custom scripts for Ardupilot. A optimized software in combination with the advanced electrical system enable the MUREX ROV V5 to glide through water and reliably carry out tasks such as placing brain coral, enabling irrigation systems, and deploy subsea cabling.

The system communicates through PWM to eight Readytosky ESCs, which drive the T200 thrusters. The Pololu 5V buck converter provides up to 5.5A for powering the BlueRobotics' Navigator Flight Controller, which communicates with the ESCs as well as the other servos for the arm through PWM, and the Murex Ethernet Switch v2.0. Video is streamed from a webcam and an IP camera. The webcam is viewed through the raspberry pi 4B and the IP camera is viewed through the Ethernet switch. Both enter the mrxPLC system, and then is decoded into Ethernet in the topside.

MUREX ROV V5 utilizes various custom PCBs, enabling various functionality at costs <30% of existing commercial options. MUREX will now provide further descriptions and functionalities for the different boards and methodologies in use.



3D Render Demonstration. Render: M. Liu.

> NAVIGATOR FLIGHT CONTROLLER

Last year, MUREX used its custom controller board called the Carrier Board, an ROV control system featuring the world's first open-source CM4-based ROV control board and the world's first open-source implementation of a USB3.0 controller in any form. However, after a devastating underwater short-circuit, the Carrier Board was severely damaged, along with MUREX's power electronics and custom ESCs (ANY ESCs).

Eventually, MUREX chose to select a commercial solution that matched the performance of the Carrier Board, landing on the Raspberry Pi 4 with the BlueRobotics Navigator Flight Controller. **The HAT is an ROV control system featuring a CM4-based ROV control board.** The board features high-accuracy sensors, industry-level control, and runs **ArduSub**, a derivation of ArduPilot for ROVs.

> NAV FLIGHT CONTROLLER Cont.

Features include:

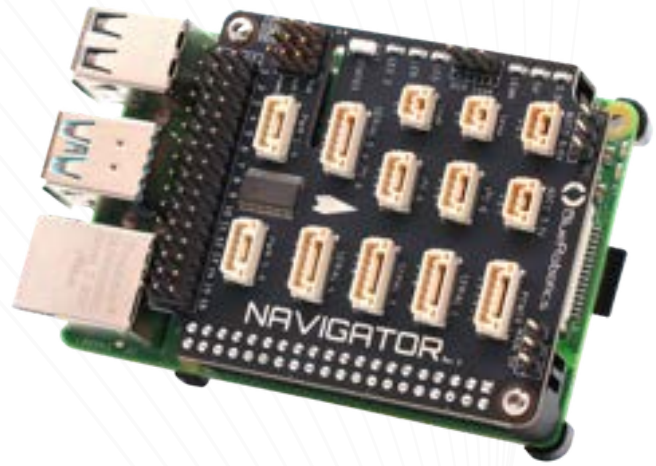
- 16 servo PWM channel outputs (8 channels are used for ESCs, and 3 are used for the claw, and additional channels for servos).
- 2 I2C ports and 4 serial ports with 3.3V logic on each port and 5V tolerance on serial ports.
- 6-axis IMU and dual three-axis magnetometers allowing for 10 degrees of freedom sensing (XYZ acceleration, XYZ angular velocity, XYZ spatial orientation, pressure/water column depth).
- The Navigator comes with a custom designed aluminum heatsink that fits between the Navigator and Raspberry Pi and allows the Raspberry Pi to operate at high CPU usage in poorly cooled environments.

> Pololu 5V Buck Converter

The D36V50F5 Pololu Buck Converter is a high-performance, synchronous switching step-down (or buck) voltage regulator that efficiently generates a fixed 5V output from input voltages as **high as 50V**. Its compact footprint, measuring just 25.4 mm × 25.4 mm, makes it an ideal solution for space-constrained applications requiring substantial current delivery

Power Board Features:

- **High Efficiency & Power Density:** Capable of delivering continuous output currents up to 5.5A.
- **Wide Input Range:** Supports a broad operating voltage range from approx. 5.3V up to 50V.
- **Advanced Protection:** Features integrated reverse-voltage protection (up to 40V), over-current and short-circuit protection, as well as over-temperature shutdown to ensure the longevity of both the regulator and connected electronics.



*Navigator Flight Controller + RPI4.
Photo: BlueRobotics*

> ETHERNET SWITCH

The mrxSwitch v2.0 is **the world's smallest and lowest cost ethernet switch**. With a focus on minimizing physical footprint and cost, the MUREX Ethernet Switch utilizes external magnetics, a high-performance unmanaged switch IC, and 1.25mm pitch Fast Ethernet (100BASE-TX) connectors. **It cuts commercial costs by 90% and acts as the central communications center of the MUREX ROV, combining the 2 IP cameras, the LX200V30, and the BlueRobotics Navigator Flight Controller.** This board was developed out of necessity as full-size Ethernet switches were too large to fit into the system and commercial options were priced extremely high.



*Image of Pololu 5V Buck Converter.
Photo: Pololu*

> ETHERNET SWITCH Cont.

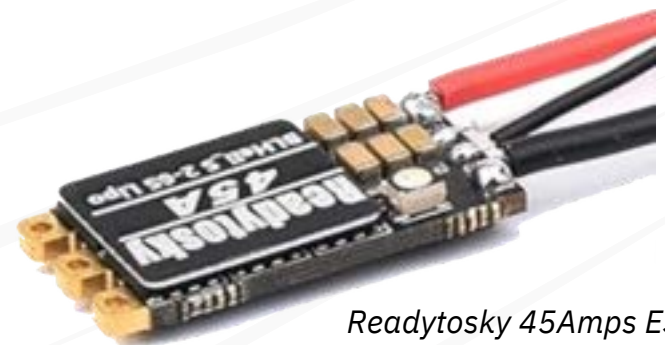
Features include:

- 5 802.3u compliant Ethernet ports with the IC Plus IP175G.
- 4.5 - 15V protected input through the LM1117MP-3.3 800mA LDO.
- Direct 3.3V power input for high efficiency.



> mrxPLC AND TETHER ELECTRICAL

MUREX has conducted extensive research and development on a novel galvanically isolated orthogonal frequency division multiplexing (OFDM) system across the power tether, **allowing our robot to have over 30-60 MBits of data bandwidth with only power and ground on our tether.** A system explanation diagram is provided in the Topside System section. We have named this development the MUREX Power-Line Communication System (mrXPLC). It enables the robot to use only two wires for the tether, minimizing cost and possible damage. This system is even more effective for high-voltage tethers.



Readytosky 45Amps ESC
Photo: Readytosky

> CONNECTORS AND WIRING

To comply with ELEC-017R, all wiring is standardized into either: Molex Picoblade/Header Pins, Molex Mini-Fit, WAGO, or heatshrunk. All data lines are Picoblades or 2.54mm header pins for their compact size. All high power connections are Molex Mini-Fit or WAGO connects if on a high power bus (like main 12V).

> Readytosky 45Amps ESCs

Last year, MUREX used RuiBet's 4 in 1 ESC boasts a compact design. Though the ESC saved space, the 4 in 1 esc have a higher chance of overheating, is costly to repair and more vulnerable to potential leaks into the enclosure.

This year MUREX decided to use Readytosky 45Amps ESCs. The Readytosky ESCs uses the latest EFM8BB21F16G high speed control chip, have built in protection and golden plating. MUREX reflashed the original drone motor parameters with BLHeli_S firmware modelled from the BlueRobotics Basic ESC to enable underwater thruster compatibility and maximum performance.



MUREX
Enclosure.
Photo: C.
Mamolo



Left to Right: Picoblade, Mini-Fit (Molex), WAGO 221 (WAGO)

SOFTWARE SYSTEM

Before settling on MRX, a **modified codebase upon Ardupilot tailored for our system**, we extensively tested alternative control systems. Our codebase has seen 3 major revisions, each with its own benefits and disadvantages. Using MRX ensures that we make full use of our ROV capabilities.

Control System	System Coverage	Setup Difficulty	Debugging Difficulty
MRX V1: Python	Low (no sensor integration)	Low	Low
MRX V2: Rust	Medium (telemetry collected from most sensors + minimal active monitoring)	High	High
MRX V3-V5: Ardupilot	High (active stabilization + real-time telemetry)	Medium	Medium

By using an off-the-shelf approach for programming we spent our time modifying the codebase, tailoring it to our system rather than writing our own system and fixing bugs as they arise. This way, we ensure that the minimum viable system worked and MUREX spends time optimizing a system that already worked reliably and consistently. **ArduSub fulfills many of our system requirements but falls short of a few important ones:** thruster control, camera integration, and peripheral arm control. The final state of our codebase can be split into the following categories: ArduPilot tooling, Lua Scripting, Component Test Scripts, ANYESC Firmware, MASCP, and Diagnostics Program.

../ ARDUPILOT TOOLING

ArduSub is the glue that brings together the electrical system. A well-designed control system is the crux of MUREX's granular and reliable driver control. A 22-state Extended Kalman Filter (EKF) accurately estimates the ROV's attitude and heading by **fusing sensor data from our IMU, gyroscope, magnetometer, and depth sensor**. ArduPilot's advanced EKF and Attitude and Heading Reference System (AHRS) allows for active stabilization on all 6 degrees of freedom, ensuring that the ROV only moves when intended. Active stabilization corrects imperfections in the ROV construction allowing for more flexibility in component placement around the ROV. Any imperfections in buoyancy and balance become unnoticeable when stabilization active.

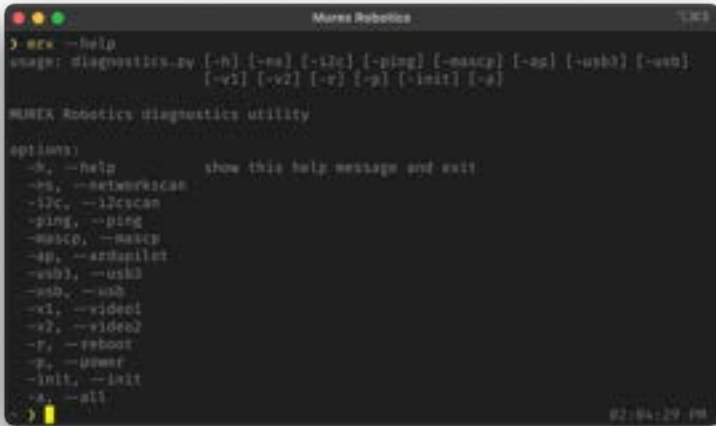
Our driver interface/ground control system is also part of the ArduPilot software suite. MUREX uses a custom version of QGroundControl (QGC) compiled specifically for our topside computer to **aggregate telemetry and communicate instructions** from the driver to the ROV. QGC greatly simplifies the testing and tuning of the system. Our programming and electrical teams can focus on parts of the system that were developed in-house without worrying whether a bug is caused by the systems that control it or the systems that were built to observe it.



Ardupilot Interface. Photo: F. Liu

./ LUA SCRIPTING

We use Lua Scripting with ArduPilot to extend the functionality of ArduSub to the **MUREX ecosystem without increasing its complexity**. ArduPilot exposes a Lua Scripting API that supports reading and modifying the execution of ArduPilot.



```

> mrx --help
usage: diagnostics.py [-h] [-n] [-i] [-p] [-m] [-a] [-u] [-v] [-x] [-y] [-z] [-r] [-p] [-i] [-a]
MUREX Robotics diagnostics utility

options:
  -h, --help            show this help message and exit
  -n, --networkscan     scan for network devices
  -i, --ipscan          scan for IP addresses
  -p, --ping            ping the specified IP address
  -m, --mascp           connect to the MASCOP
  -a, --ardupilot       connect to the ArduPilot
  -u, --usb             connect to the USB
  -v, --vid            connect to the video
  -x1, --video1         connect to the video 1
  -x2, --video2         connect to the video 2
  -r, --reboot          reboot the robot
  -p, --power           power the robot
  -i, --init            initialize the robot
  -a, --all             all
  
```

MRX Diagnostics “--help” Screen. Photo: A. Ünver

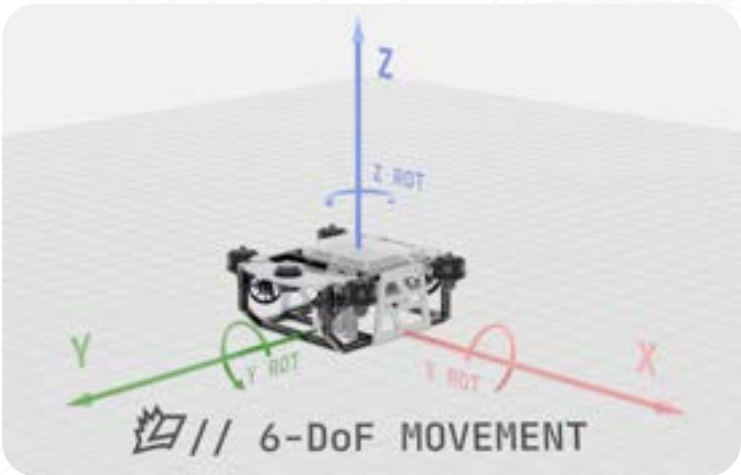
/ COMPONENT TESTING SCRIPTS

In addition to the tools provided by ArduPilot, we also have our own set of scripts to ensure that modifications to the electrical system maintain functionality. Most of our test scripts are written in the Rust programming language and are cross-compiled to run on the MUREX Carrier Board. Before switching to ArduPilot, MUREX conducted extensive research on using Rust for embedded and high-level applications. Ultimately, we found that the Rust ecosystem was underdeveloped and too young to be used effectively in our system. Since the scripts worked well and did not need to be re-compiled, we continued to use them to test the system integrity even after switching to ArduSub.

../ DIAGNOSTICS AND TESTING

The diagnostics program is a **Python script that can run on any topside computer**. It helps facilitate testing and brings together many of the component

testing scripts. The diagnostics program also helps us rapidly deploy the ROV and start the camera streams. It automatically goes through all safety and initialization steps required for a successful deployment. The diagnostics program also abstracts some steps of deployment since it does not require connecting directly to the robot, only being present on the same network.



6 Degree of Freedom Movement Diagram. Render: B. Huang

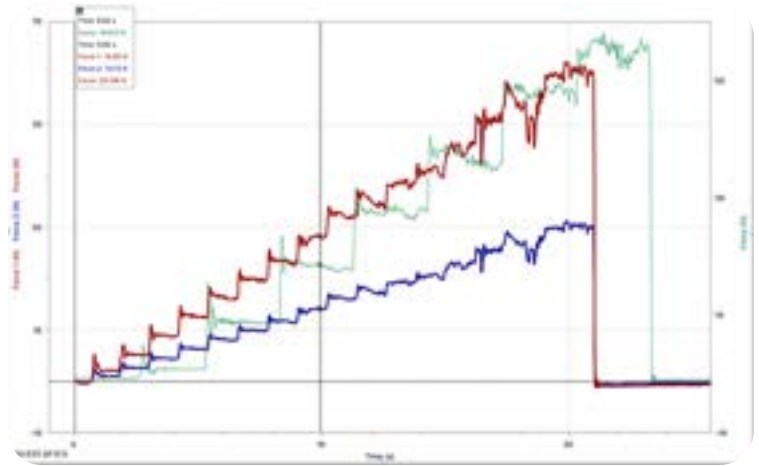
PROPULSION

The MUREX propulsion system consists of 8 Blue Robotics T200 thrusters driven by MUREX ANYESCs. The MUREX ROV has 8 thrusters in a vectored configuration, allowing movement in all 6 DoFs. This is a standard thrust vectoring configuration, allowing for rapid electrical and software expansion. **Using our custom control system framework, mrx, the MUREX ROV’s advanced 10-DoF electrical system allows the robot to stabilize and depth-hold** at any location and depth in the deployment environment. Their external position to the ROV, provides a greater torque and stability but increases chances of entanglement with tether, and SMART Cables. This increased chance of entanglement has been solved with the use of reflective tape and thruster guards around all directions off the thrusters.

MUREX conducted extensive experimentation of the current draw and efficiency of trapezoidal, field-oriented control (FOC), and sinusoidal drive of brushless DC motors. FOC offers clear advantages of higher torque and efficiency at the cost of higher computational requirements.

Our schedule didn't allow for further experimentation of FOC driving of BLDCs, so we continued our use of trapezoidal drive ESCs running a custom version of the BLHeli_S firmware.

BLDC Control Method Comparison:



FOC and Trapezoidal Thruster Profiling. Photo: A. Ünver

Control Method	Trapezoidal	Field-Oriented Control	Sinusoidal
Software Complexity and Motor Efficiency	Low	High	Medium
Maximum Speed	High	High	Medium
Noise	High	Low	Low
MOSFET Switching Losses	Low	High	High
Final Choice	Selected	Under development	Unsuitable

//BUOYANCY AND BALLAST

The MUREX ROV was specifically designed with buoyancy and ballasts in mind. The mechanical design used CAD software such as Onshape to **determine the center of gravity** and the **density** of the robot. With an overall weight of **10.5 kg** and a density slightly greater than that of water due to the aluminum enclosures, pool noodles were strategically placed to achieve a neutrally buoyant ROV with a center of mass slightly below the main enclosure. This is due to SRPP's density of around 0.96g/cm^3 . In combination with the control system, the **MUREX ROV can hover at any position** when completing tasks which is an immense aid to the driver who wishes to complete tasks designated in the RFP requiring the most accuracy.

The initial mass of the mrxFLOAT rests at about **2795 g** without weights, but we have added eight stainless steel weights to make it neutrally buoyant. Once **1000mL** of water is taken through the syringe, the mass increases to **3795g** while the volume of the float stays constant at **2875 cm³**. Thus, the intake of water changes density from **0.97 to 1.32**, resulting in descension. The inverse is repeated for ascension.

//BUOYANCY MODULE (mrxFLOAT)

The **mrxFLOAT** consists of an open syringe moved by a continuous rotation goBilda servo motor and lead screw mechanism, resulting in a buoyancy engine that **changes its volume by approximately 1000mL**. This particular motor was chosen for its **high torque and fast rotational speed**. This provides rapid movement and precise depth control. We also incorporated custom endcaps CNC'd out of 6061 aluminum as a cost-reduction measure.

The main fuselage is constructed from 4 inch polycarbonate tubing, which is more than capable of withstanding **14 feet of water pressure**. Ballast is provided by eight stainless steel weights mounted to the exterior by a 3D print. We ensure the buoyancy module is completely waterproofed through **several layers of redundancy** - the syringe mount and electronics enclosure are both sealed with O-rings, as well as all the penetrators and hex nuts.

The enclosure holds a 6V battery holder, an inline 5.0A fuse, SPST switch, a custom mrxFLOAT Carrier Board which carries a ESP32 LoRa V3, and a GoBilda 2000 Series Dual Mode Servo. For communication, MUREX considered options such as Wi-Fi and Bluetooth, but preferred the **simplicity and long range** of LoRa. The ESP32 LoRa V3 in the float transmits signals (915 mHz) consisting of the ROV's company number, local time, and depth in five second intervals throughout its descent and ascension. Another ESP32 LoRa V3, located on the surface, receives these signals and data points in which MUREX can then graph.

Using the **BlueRobotics BAR02 Depth sensor**, and their MS5837 library, the ESP32 is able to successfully communicate the depth of mrxFLOAT. In both versions, the enclosure has been verified to comply with MECH-001 (pressure tested to 5m water column depth). The pressure relief system consists of a top cap that disengages from the acrylic tube in the event of high pressure, which is also paired with a standard BlueRobotics pressure cap rated to 12 psi. Additionally, to follow safety specification ELEC-NDR-005, a 5.0A fuse is attached within 5cm of the power wire of the battery.



mrxFLOAT. Photo: A. Baykrayter

>mrxFLOAT Carrier Board

mrxFLOAT Carrier board is a custom board designed **this year** to fit on the mrxFLOAT, aiming for more secure wire connection and better wire organization.

Features include:

- 7 servo PWM channel outputs
- screw terminals for more secure connections
- a 3.3V output buck converter with wide range of input (4.5V - 17V)



3D Render of PCB.
Render: K. Chen

// COST SAVING

At MUREX Robotics, our approach to choosing the right components is very simple: **if we find that a task can be done better than commercial alternatives or for a lower price, we design and test in-house. If industry standards exceed our team's capabilities for a reasonable price, we use the commercial alternative.** This rationale is demonstrated extensively throughout all subgroups at MUREX. We make extensive use of custom boards in our electrical system because they greatly reduce the cost and space while increasing performance relative to what we could purchase. The performance and cost of the electrical system are crucial to exceed our customer's requirements as it allows more budgeting towards other areas of research and development while providing a state-of-the-art control system that can adapt to any deployment environment. The custom parts in our frame design were scrutinized to ensure that the value they contributed justified the added complexity.

To conserve cost, we have re-used the ROV's controller, servos, and various miscellaneous hardware, re-integrated our custom electronics, and re-implemented our old ROV electronics enclosure as an effective solution for the mrxFLOAT.

A major innovation this year was **custom waterproof servo cases** for the team. In previous years, we utilized cases from Blue Robotics, which although very effective were a huge monetary drain. Through months of in-house testing, we designed resin-printed servo casings with spring-loaded shaft seals that could hold 25 bar for over 20 hours. These casings cost only \$26.07 to manufacture, **7% of the original \$375.00 cost.**

System	Function	Prototype Price (ea)	Commercial Option Price (ea)	Cost Savings
MUREX Ethernet Switch	Packet switching on robot network	\$9	Blue Robotics Ethernet Switch: \$175 BotBlox Switchbox: \$72	95%-59%
MUREX Waterproof Servo Casings	Keeps water from damaging servos	\$26.07	Blue Robotics SER-201X Economy \$375 (cheapest variant)	93%
OFDM Data Injection (mrXPLC)	Data transfer across tether	\$0	Fathom ROV Tether: > \$220 (increases with length)	N/A (Zero Cost)
Total		\$171.07	\$1770.91	>89%

Notes: MUREX prices are based on JLCPCB production cost – tax, shipping, and tariff included. Commercial prices do not include tax and shipping. Most commercial options lack features and power protection compared to MUREX systems. Please see Control/Electrical System.

> ELECTRICAL R&D

Much of the beginning of the year was invested in conducting research and development of the electrical system. Our initial designs lacked EDS, transient, and other circuit protection systems. The PCBs were also routed inefficiently, resulting in unnecessarily dangerous and large boards. **After multiple revisions on each of our electrical systems, we were able to create reliable boards that implement state-of-the-art protection and performance improvements.** All R&D is conducted under the mrxEE (MUREX Experimental Engineering) subsidiary of MUREX.

> ELECTRICAL TESTING

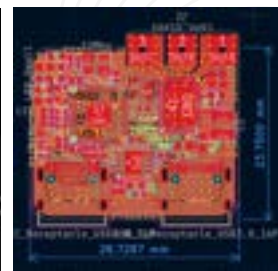
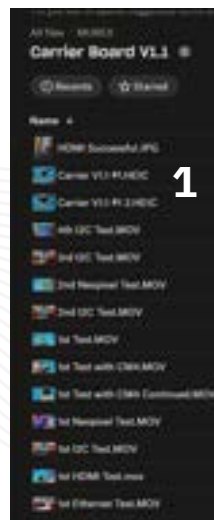
MUREX follows rigorous testing procedures and a system to version manage circuit board designs. **We have developed the follow procedure:**

1. Research and determine main components.
2. Design your schematic (KiCAD eeschema)
3. Design your PCB (KiCAD pcbnew)
4. Design your silkscreen (KiCAD pcbnew)
5. Tapeout verification with the team (Discord)
6. Production with Fabricator (JLCPCB)
7. PCB Testing (mrxEE)
 - Incremental testing of every feature. Every test must be recorded and marked. (Dropbox)
8. Update documentation and generate renders. (Web Dev + Blender Visualization)

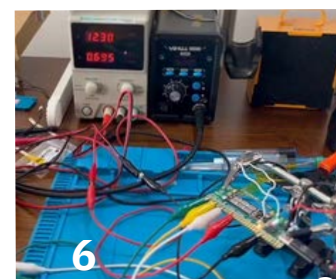
Through this process, we use GitHub to version manage as well as share our work with others in the underwater ROV community. Again, our work is fully open-sourced and documented.

> METHODOLOGY

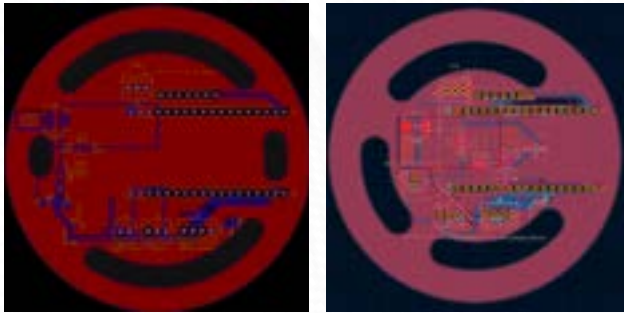
MUREX's extensive use of custom electrical, software, and mechanical components result in high performance at the expense of complex testing methodologies. **Our testing methodology focuses on variable isolation and finding the root of the problem as quickly as possible.** Our mechanical team utilizes extensive use of iterative design and 3D printing to improve designs. We conducted 12 pool tests this year to maximize iterative design potential.



STESC ->
ANYESC ->
MINI_FOC ESC.
Photo: M. Liu.

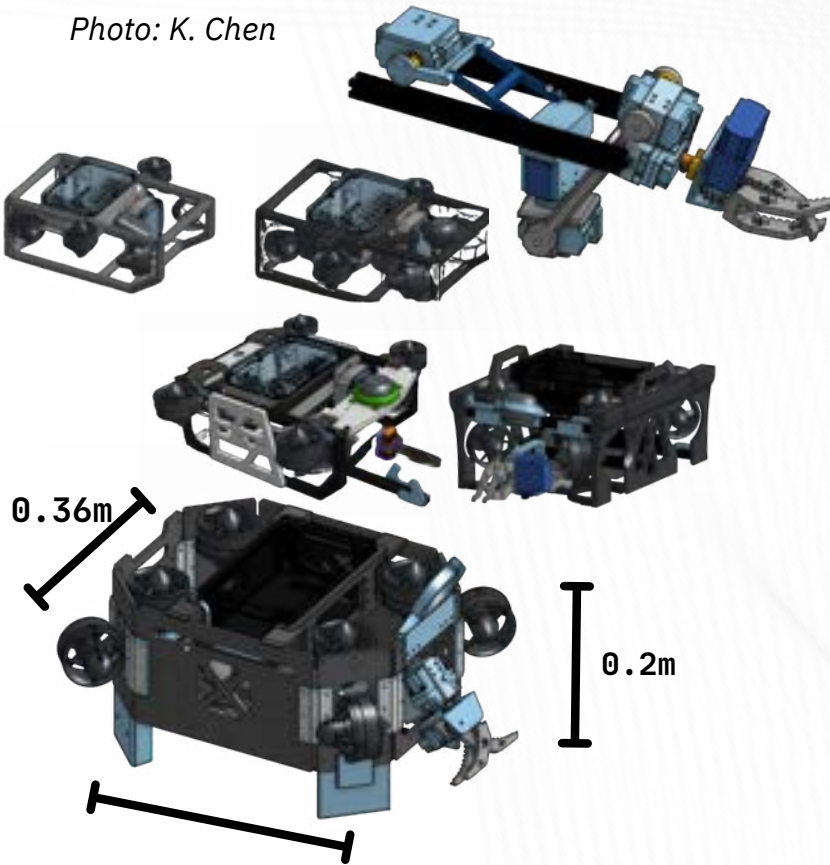


Explanations in footnotes, section [a]



mrxFLOAT Carrier Board V1 -> V2 | 15% area decrease

Photo: K. Chen



0.45m

From top to bottom, left to right:

Early 6DOF claw prototype

V1.0, First Exoskeleton Frame ~ bulky, unstable and weak acrylic base

V2.0, Hybrid Winged Design ~ unreliable vertical profiling due to water resistance, no manipulator space

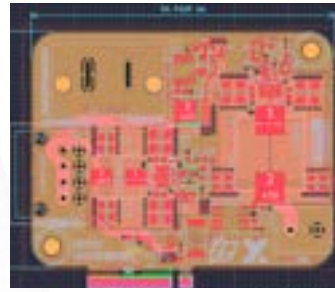
V3.0, Medium Wing Design with Front Bezel ~ Thruster Mounting Unstable

V4.0, HDPE Design ~ HDPE material too soft, not enough modification potential after manufacturing

V5.0, SRPP Design (CURRENT) ~ stable, modular design, easy to modify

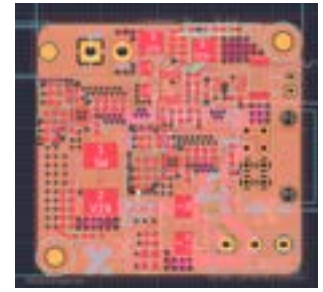
Photos: F. Liu, O. Chang x4, F. Liu

CRITICAL ANALYSIS AND TESTING CONT'



Power V1 -> V2 | 20% area decrease.

Photo: M. Liu



>MECHANICAL TESTING

MUREX's designs are rapidly prototyped through 3D printing to ensure thorough testing. Designs are modified until their versatility and coordination with other subsystems is maximized. Special care is taken to make sure all mechanisms are waterproofed. For example, the custom servo casings were tested at **25 bar for 24 hours**, as well as **left underwater for 3 days**, before deemed as waterproof.

>MECHANICAL R&D

Over the summer, MUREX's mechanical team researched into various frame and claw designs. Design matrices were used to narrow down options, but months of prototyping were still required. Through this, we have produced **5 major chassis designs, 3 float designs, 3 methods of servo case waterproofing**, and **5 versions of a claw** to achieve our final products.



Shaft seals tested by MUREX

left to right: spring-loaded, mechanical pump, bore-sealing

Photos: McMaster-Carr



Casing pressure after 24 hours.

Photo: F. Liu

Casing CAD and final.

Photos: F. Liu



The waterproof servo casings feature an O-ring and four screws which are offset from the interior. The shaft is waterproofed by a **spring-loaded rotary shaft seal** from McMaster-Carr, chosen after testing multiple options. The sides feature four inset nuts for ease of mounting. MUREX initially used epoxy-coated PLA for the material of the casing. However, we quickly realized that it affected the tolerances, compromising the O-ring seal. Using a design matrix, we decided to pivot to **Ledo 6060 resin**.

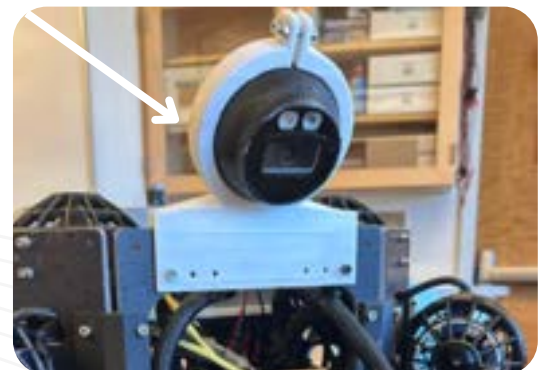
Description	Cost Efficiency (max 10)	Watertightness (max 15)	Concerns (min -10)	Total Score
JLC CNC from BJ-316L stainless steel	Quoted \$877.92 +0	+15	Very hard to modify -5	10
JLC 3DP from Ledo 6060 resin	Quoted \$183.55 +8	+12	Hard to modify -4	16 our final choice!
3D-printed design (PETG) + Dichtol AM (a substance that waterproofs 3D prints)	3D-printing costs negligible, Dichtol cost \$159.00 / 1L +9	+12	Unfamiliar with Dichtol, not sure if it will affect tolerances -8	13

PAYLOAD & TOOLS

The MUREX ROV V5 features two cameras, each providing a deliberate, unique view. The back camera is an Insta 360 Link 2 mounted at a 70° angle on the chassis's front plate. This camera faces the pool floor, providing a wider bird's-eye view of the ROV's surroundings. The second camera is an Amcrest IP5M-T1179EB-28MM angled 70° downwards in the back of the ROV. It provides a direct view of the 3DOF claw and its surroundings.

Our ROV's manipulator is a 3D-printed claw that features **3 degrees of freedom**, pitch, roll, and open-close. This maneuverability renders precise tasks such as retrieving coral by the substrate effortless. Its **continuous rotation function** allows for rapid removal of biofouling. Custom-designed herringbone gears, printed with PETG for superior strength, provide an increased grip and reduced chance of wear. Ceramic ball bearings are utilized to lessen friction in the prongs. An innovative **three-pronged design with interlocking tips** provides a secure grasp around objects of all shapes and diameters, from the micropile pin to the eDNA sensor.

MUREX's mechanical team had initially designed a claw with 6 degrees of freedom. However, we eventually decided it would be more pragmatic to have a smaller claw. The weight of the extra servos as well as the large range of movement in the 6DOF claw would interfere with the ROV's stabilization. There were no tasks outlined in the RFP that would benefit from the extra degrees of freedom enough to justify these setbacks.



Left to Right: 3DoF Claw, Back Insta360, Front Amcrest. Photos: F. Liu

// SAFETY RATIONALE

MUREX Robotics regards safety as the **top priority at all times**, whether it be during research and development, large-scale tests, or deployments. Our robot has a wide range of safety features. This includes MUREX's IP20-grade thruster guards, electrical transient spike protection, system voltage and current monitoring, mechanical limits, and an extensive software pre-arm checklist. Our advanced electronics and software system actively monitor voltage and current in the system, the power loss across the tether through a comparison of topside power supply and ROV power reception, temperature, pressure, moisture, and gas resistance monitoring, AHRS heading system calibration, and more. The claws have programmed and mechanical limits to prevent unwanted rotation, and the frame has no sharp edges to prevent damage to its deployment environment. Every electrical system is assembled in accordance with the Restriction of Hazardous Substances Directive (RoHS) such that in the case of a failed deployment, the electronics contain acceptable levels of hazardous material. In addition, we have devised an extensive safety protocol for each subgroup. **Summaries of the protocols are listed below.**

MECHANICAL: Wear appropriate personal protective equipment (PPE) at all times. This includes, but is not limited to: safety goggles, gloves, closed-toed shoes, and hearing protection. When operating heavy power tools, a proctor must be present. In addition, all common safety protocols should be followed.

Rationale: Preventing injury when constructing and testing the robot.

ALL SUBGROUPS: A thorough safety inspection is performed before and after each deployment.

Rationale: Robot performs as expected and is maintained in good condition.

WATERPROOFING: Pressure test to 15 inches of Hg (in compliance to MECH-001) after any modification or opening of any sealed system. The pressure may not drop more than 3400 Pa (1 in Hg) after 1 hour, and 17000 Pa (5 in Hg) after 24 hours. In addition to waterproof servo casings, the servos present in the ROV are filled with mineral oil and coated with epoxy. The lower specific gravity of mineral oil compared to water prevents the upward flow of water through the downward facing shaft into the servo.

Rationale: This protocol ensures that the robot maintains its watertight integrity at any point during testing, repairs, and deployment.

Electrical: Verbally announce and count down "power on" and "power off" while recording the system in question for any live testing. *Rationale:* MUREX keeps video records of every electrical test should further analysis be required. Verbal confirmation allows every member in the vicinity to either clear away or pay specific attention.

Electrical: All wiring is secured and all persons maintain a distance from any exposed wiring. *Rationale:* This protocol protects both team members and the equipment. It means even if the wiring is accidentally jostled, all systems remain unaffected.

SOFTWARE: Hard-programmed limits present on all moving systems.

Rationale: Limits ensure that the robot will not perform movements outside of its expected range.

SOFTWARE & ELECTRICAL: Independently verified testing on all subsystems before integration.

Rationale: All parts of the system must be tested and known to be electrically and programmatically sound before further integration.



> DEPLOYMENT SAFETY CHECKLIST

Prior to and after every deployment, the team will have their respective members for mechanical, programming, and electrical check every system with audible responses. ***Our Chief Safety Officer (CSO) Hopson checks all protocols.***

- Chassis supports at least 600N force applied. **“CHASSIS CLEARED”**
- Thrusters attached securely + cannot move over $\pm 2\text{mm}$ in any direction. **“THRUSTERS CLEARED”**
- All propellers, servos, and any other motors are free spinning. **“MOTION CLEARED”**
- All manipulation devices attached securely and lubricated. **“CLAW CLEARED”**
- Tether supports weight of robot. Spaced out flotations securely mounted to tether. **“TETHER CLEARED”**
- All potential ingress points lubricated and sealed with lubricated O-rings. **“INGRESS CLEARED”**
- All vacuum plugs and seals free of debris and other unwanted substances. **“SEALS CLEARED”**
- All wiring in robot, topside, and float secured and unexposed. Main tether not continuous (shorted). **“WIRING CLEARED”**
- All software is launched and the topside computer has over 50% charge. **“PROGRAMMING CLEARED”**
- Topside powered, controller connected, demo team ready for power on. **“TOPSIDE CLEARED”**
- The topside emergency stop button “OFF” (pressed in). If all other protocols are cleared, the demo team announces “ON STANDBY”. If all protocols are followed correctly, the safety manager announces **“READY FOR POWER ON”**.

> PRE/POST DEPLOYMENT SAFETY PROTOCOL

Demo team conducts final visual inspection of topside wiring and setup. If passing inspection, demo team announces **“POWER ON CLEARED. POWER ON IN... 3... 2.... 1”**. If not passing inspection, demo team announces “POWER ON WRONG”. Appropriate measures then taken.

Demo team moves emergency stop button to the “ON” position (pulled out). The motors produce power up (3 beeps in increasing pitch) and arming sequence (1 high pitch beep, then 1 low pitch beep). An electrical member on standby announces **“MOTOR ARMING CLEARED”**.

Demo team waits for “MUREX TOPSIDE” Wi-Fi SSID to appear or is assigned an IP address by the topside router depending on the connection method. **“CONNECTION CLEARED”**.

Demo team enters the OpenWRT portal (192.168.8.1) and verifies the following devices are listed: 1. Amcrest Camera 2. Reolink Camera 3. MUREX Carrier Board and demo team executes system check software. **“SYSTEM CLEARED”** Demo team initializes all softwares. **“SOFTWARE INITIALIZED”**, then **“ROBOT IS ARMED”**

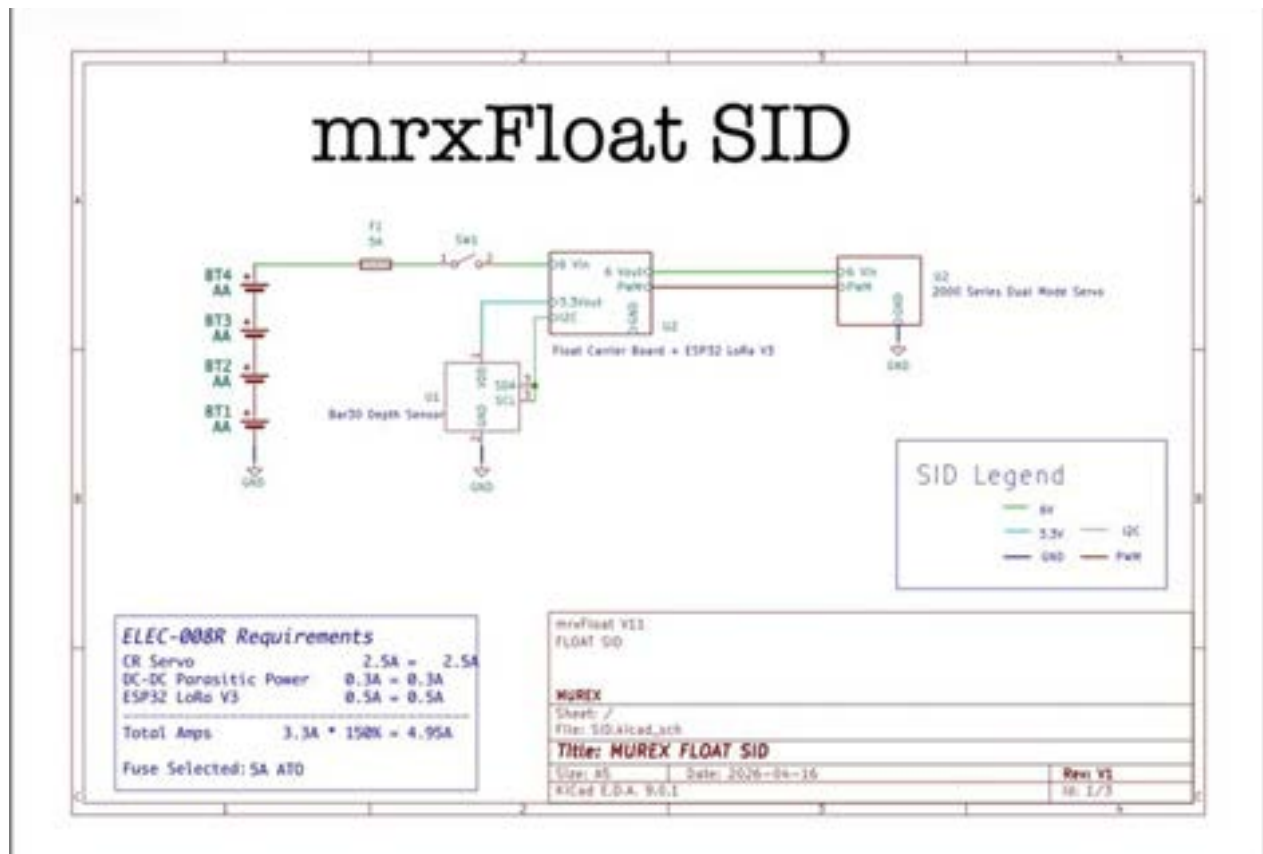
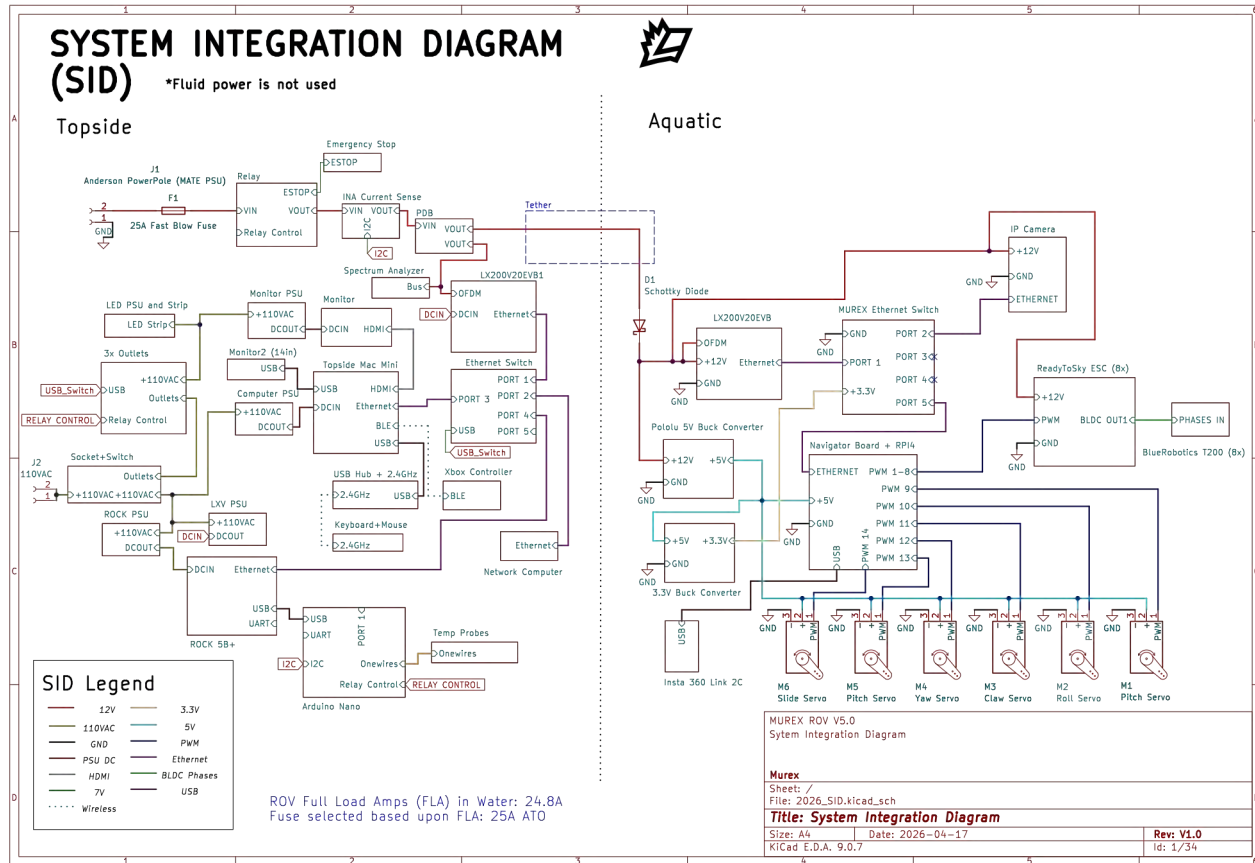
Demo team conducts a dry run of the thrusters and the cameras are verified. **“TESTING THRUSTERS”**, **“TESTING CAMERAS”**. Tether managers respond **“THRUSTERS GOOD”**, **“CHECKING CAMERAS”**.

Demo team responds **“CAMERAS GOOD”**

Tether managers pick up the robot and rotate in all axes. **“ROTATING <ROLL/PITCH/YAW>”**. Demo team responds **“<ROLL/PITCH/YAW> GOOD”**

If all systems are intact, the demo team announces **“ALL SYSTEMS GOOD”**. The safety manager echoes **“READY FOR DEPLOYMENT”**

Tether managers lower the ROV into the water. **“ROV DEPLOYED”**. Tether managers ceases communication with the demo team except for tether management issues.



// BUDGETING PROCESS

MUREX manages its budgeting through a centralized **Google Sheets** tracker that combines purchase orders, vendors, item links, quantities, categories, and realized costs in one place. Before each purchase, we recorded the item, vendor, expected cost, and technical purpose, then submitted the request through Phillips Exeter Academy's purchasing process. After ordering, we updated the sheet with final cost, shipping when applicable, and delivery status. This system allowed us to compare projected costs with actual spending, monitor inventory, avoid duplicate purchases, and adjust quickly as the vehicle design evolved.

For the 2025–2026 season, MUREX received a \$3,750.00 Phillips Exeter Academy build allocation, which is the budget tracked directly on the order sheet. The sheet currently records \$2,684.87 in order-level expenditures, leaving \$1,065.13 remaining in the PEA-managed build budget. In addition, MUREX received \$8,476.00 in friends and family donations for build and testing, which are tracked separately from the order sheet so that school-managed purchasing and outside support remain clearly distinguished. This process helped us maintain accountability, respond to design changes, and preserve funds for testing, replacement parts, and final competition preparation.

// PURCHASED ITEMS BY VENDOR

Below are all reused and purchased items divided by category. **All currency in USD.**

Item	Price
Bought This Year	
Amazon	\$1,010.22
McMaster-Carr	\$372.99
WestCoast Products	\$332.49
Blue Robotics	\$185.00
JLCPCB	\$183.55
ServoCity	\$162.75
SparkFun	\$162.13
goBILDA	\$115.50
Polycase	\$70.47
Home Depot	\$62.30
PVC Fittings Online	\$15.54
DigiKey	\$11.93
Total recorded expenses	\$2,684.87
Reused	
Reused 3xT200 BlueRobotics Thrusters	\$1,500.00
Reused Aluminum Extrusions	\$500.00
Total Reused	\$2,000.00

// OVERALL FINANCIAL SUMMARY

Phillips Exeter Academy school build allocation tracked on the order sheet: \$3,750.00
 Friends and family donations tracked separately from the order sheet: \$8,476.00
 Total build and testing funds available: \$12,226.00
 Recorded order-sheet expenditures: \$2,684.87
 Remaining build and testing funds: \$9,541.13
 Estimated value of reused items: \$2,000.00
 Estimated value of donated services: \$3,000.00
 Estimated travel expenses: \$28,000.00
 PEA travel allocation for the World Championship: \$28,000.00
 Total cash budget (build + travel): \$40,226.00

// ITEMS BY CATEGORY

Category	Items
Electronics & Computing	Pixhawk 6C flight controller and cable set, Raspberry Pi 4B 4GB, ESP32 LoRa V3 modules, BAR02 depth sensors, ReadytoSky 45A ESCs, TP-Link Ethernet switch, 12V to 3.3V buck converters, RakWireless LX20V200 PLC modules, Barlus underwater camera, 18-gauge tether wire, 18-gauge 2-conductor wire
Frame & Structural	PVC pipe and fittings (½", ¾", 1", 1½", 2", 3" — tees, elbows, crosses, sideouts, couplings, reducer bushings, end caps), WestCoast ¼" SRPP sheets, ¼" aluminum rods, Polycase AN-23P NEMA enclosure, corrugated plastic sheeting, PEX tubing and fittings
Actuators & Motion	goBILDA 2000-series CR servo, ServoCity servo programmer, goBILDA 6mm round-bore hubs, servo-to-shaft couplers, ½" servo shafts, 12mm bore clamping hubs, carbon steel Acme lead screws, connecting rods, threaded rod, shoulder screws
Sealing & Hardware	Rotary shaft seals, Buna-N O-rings, O-ring-loaded U-cup seals, stainless steel sealing nuts, reinforced sealing washers, heat-set inserts, screws and hardware, Blue Robotics OK plugs, spring-loaded shaft seals
3D Printing	Resin-printed servo cases (JLPCB)
Misc & Testing	Stainless steel ballast weights, syringes, bubble wrap, chenille pipe cleaners, vinyl ID numbers, brick ballast, polypropylene rope, bucket and lid, milk crate, screw hooks, O-balls

// TRAVEL EXPENSES

Category	Price
Airfare	12000
Lodging	5000
Meals	3300
Ground Transportation	2000
ROV Shipping and Freight	2500
Competition Registration Fees	500
Travel Insurance	1000
Passports and Documentation	500
Miscellaneous & contingency	1200
Total Estimated Travel Expenses	28000

// DONATED ITEMS AND SERVICES

Phillips Exeter Academy provides workshop access, tools, 3D printers, pool testing time, and faculty mentorship, all of which significantly reduce operating costs and expand our ability to prototype, test, and iterate. We estimate the fair market value of these donated services and resources at \$3,000.00. In addition, MUREX received \$8,476.00 in friends and family donations, which are tracked separately from the order sheet. Together, this institutional and community support has been essential to the development of our ROV and the continuation of the program.

ACKNOWLEDGEMENTS AND REFERENCES

PURCHASES / VENDORS

- Axon Robotics for supplying servos.
- McMaster-Carr, Amazon.com, Digikey, Mouser, Polycase, Fabworks, Misumi, Lowe's, Blue Robotics, Adafruit, GoBilda, GetFPV, and others for supplying parts.

THANK YOU TO:

- **MATE II** for hosting the MATE ROV Competition
- **MATE ROV NE Regionals** for invaluable advice and providing this opportunity
- **The Phillips Exeter Academy Theater Department** for providing CNC machining
- **JLCPCB** for printed circuit board production
- **PTC OnShape** for free student use of their CAD software
- **KiCAD** for electronics design software
- **Bambu Lab and Prusa Research** for innovating 3D printers

ONLINE RESOURCES

- TI, STMicro, IC Plus, Bosch Sensortec, TE Connectivity, Diodes Incorporated, Winbond, Molex, Qualcomm, Broadcom, Raspberry Pi Foundation, Rockchip, Allwinner, Logitech, TNK, Murata, Panasonic, WAGO, Würth Elektronik and others for providing online resources and whitepapers. Our system either includes/uses electrical components designed by the above companies or has read whitepaper publications. **However, the team did not receive advice from any company listed above.**

SINCERE GRATITUDE TO:

- **Phillips Exeter Academy** for providing space, funding, and support to the MUREX Robotics Company.
- **John H. Hessel '52 and Sidney A. Hessel** for providing funding as part of the Phillips Exeter Academy Hessel Fund.
- **The Mahdavian Family** for a generous \$8,476 USD donation for future years
- Our mentors, **Charles Mamolo, Julie LaFranzo, and Courtney Shaw** for their invaluable advice, time, and support

> FOOTNOTES

- [a] 1. Testing videos for all PCBs are stored on Dropbox
- [a] 2. Detailed documentation hosted at docs.murexrobotics.com
- [a] 3. github.com/murexrobotics/electrical-2024 commit history
- [a] 4 + 5. INA226 Load Testing on Power Board
- [a] 6. ANYESC Power Testing
- [a] 7. electrical-2024 main GitHub page
- [a] 8. Carrier Board V3 USB3.0 debugging
- [a] 9. Ethernet Switch stress testing (iperf)
- [a] 10. C. Lee tests Ethernet Switch with IP camera
- [a] 11. ANYESC + ESC Carrier First Test