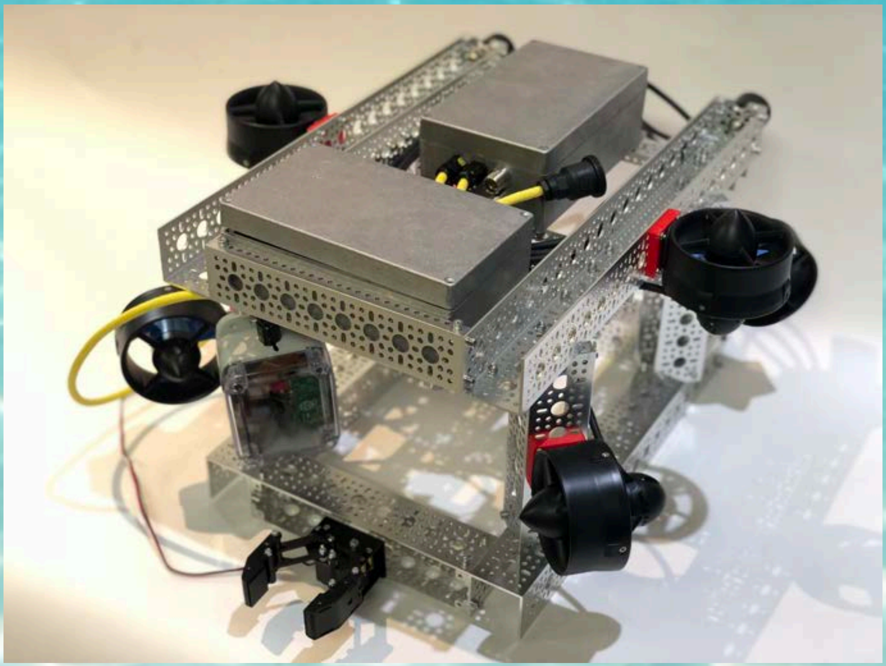
TECHNICAL DOCUMENTATION
MATE WORLD CHAMPIONSHIP
JUNE 20-22, 2024

HEPHAESTUS ROBOTICS

TALOS IV



TEAM MEMBERS

Ben Hillard	CEO
Daniel Fernandez	COO, VP of Fundraising
Bennet Menzer	CTO, VP of Engineering
Kai Herbst	VP of Software, Scheduling
Maxwell Chen	VP of Software, Safety
Uriel Marinez-Uribe	VP of Float
Blaise Benoit-Corey	ROV, Software Engineer
Nami Brown	CFO
Sophia Casaletto	Data Analysis Software
Orlando Cazales	Sensors Engineer
Olivia Chen	Sensors Engineer
Kaden Collier	Float Engineer
Autumn Feather	PCB Engineer
Julia Guth	Float Engineer
Matthew Hofmann	Sensors Engineer
Nate Hofmann	Sensors Engineer
Izaak Ocampo	Topside Engineer
Kaden Ortiz	Float Engineer
Evelyn Potts	Float Engineer
Lauren Potts	Float Engineer
Josiah Staley	Topside Engineer
Amber Williams	Float Engineer
Cole Williams	Software Engineer

MENTORS

Tim Sylvester, Head Mentor
Stefano Carpin
Holly Casaletto
Nikunj Goel
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HEPHAESTUS ROBOTICS
X-ACADEMY
SANTA CRUZ, CA USA

TABLE OF CONTENTS

ABSTRACT

Hephaestus Robotics is a high school robotics team based in Santa Cruz County, California, USA. The team operates under the X Academy nonprofit organization, functioning independently from any schools, and is supported by the Santa Cruz County Office of Education. Our team comprises students from a diverse range of backgrounds, representing a total of 13 distinct high schools dispersed throughout the county. The newest addition to our ROV design, designated as the Talos IV, is a uniquely modular design engineered in alignment with our company's mission: producing innovative remotely-operated underwater vehicles that address critical and pressing environmental challenges, while underscoring our commitment to delivering advanced solutions in underwater robotics technology. Talos IV is well equipped to work within the marine ecosystem for both observational and interactive tasks. Our unique architecture ensures remarkable adaptability to accommodate a wide range of mission-specific objectives, including interacting with underwater scientific equipment, inspecting and laying of underwater cabling, deploying and retrieving floats, and fostering the restoration of vital underwater ecosystems. Coupled with Vulcan III, a vertical profiling float, we can deploy across diverse environmental settings and facilitate remote data acquisition over time. The preservation and sustainability of marine ecosystems are crucial in advancing the objectives outlined by the United Nations Sustainable Development goals. We are positioned to effectively address these critical challenges with our well designed equipment.

The Hephaestus team works under the philosophy of specialization and collaboration, with each team member taking ownership of a specific aspect of the project, and bringing their knowledge to the broader team. Each project on the ROV and float was headed by a specific member, who then enlisted the help of or was mentored by other members.

From our modular frame and camera systems, to our custom printed circuit boards and our ROS control software, this technical document illustrates the accomplishments of our team over the last eight months.

TEAMWORK

TEAM MEMBERS

TOP ROW (L TO R): EVELYN POTTS, NATE HOFFMAN, LAUREN POTTS, MATTHEW HOFFMAN, BLAISE BENOIT-COREY, MAX CHEN, BENNET MENZER, BEN HILLARD, URIEL MARINEZ-URIBE, KADEN ORTIZ, ORLANDO CAZALES
BOTTOM ROW (L TO R): DANIEL FERNANDEZ, NAMI BROWN, OLIVIA CHEN, SOPHIA CASALETTO
NOT PICTURED: KADEN COLLIER, AUTUMN FEATHER, KAI HERBST, IZAAK OCAMPO, JOSIAH STALEY, AMBER WILLIAMS, COLE WILLIAMS
PHOTO CREDIT: REYNALDO BARRIOZ

PROJECT MANAGEMENT

COMPANY PROFILE

Hephaestus Robotics is a team of inspired robotic engineers from different schools across Santa Cruz County. We build innovative and modular ROVs ideal for many different missions, including management of observation systems, complicated interactions with undersea cables, and even steward endangered coral reef ecosystems. In addition to our ROVs, we build autonomous observational floats ready for deployment. This is our fourth year competing in the MATE ROV Competition.

The company began out of a garage during the pandemic in 2020-2021, with roughly a dozen members. They managed to rise to the new challenge and placed 7th in the 2021 MATE ROV world championship.

The following year in 2021-2022, the team size doubled and expanded operations by renting a 1,600 square foot Maker Space, which required a much more robust organization of roles. Each member was responsible for designing part of the ROV as well as part of the business aspect of the team. The team placed 3rd in the regional competition.

In 2022-2023, we had again a dozen members and focused on a reliable and efficient design. Despite the small size, we applied new skills to the ROV with a custom PCB and with several task specific tools were able to make full use of the modular aluminum frame characteristic of our ROVs. The team placed 2nd in the regional and 5th internationally.

This year, the number of students in the X Academy robotics program grew to 51 students. The students formed two teams - a Ranger team and a Navigator team. The X Academy partnered with the Santa Cruz County Office of Education, who has graciously sponsored the teams and provided a second location in Watsonville, CA. The Ranger team split the tasks between the two locations with the Santa Cruz location building the main ROV and the Watsonville location building the float.

Hephaestus Robotics is not associated with a school like other teams but rather with the X Academy, a 501(c)(3) nonprofit that provides STEAM enrichment programs to kids in Santa Cruz County. Hephaestus team members come from 13 different schools.

TEAM ORGANIZATION & ROLES

The leadership team is composed of our CEO Ben Hillard, COO Daniel Fernandez, CTO Bennet Menzer, VP of Software and Scheduling Kai Herbst, and VP of Software and Safety Max Chen. We would meet to make important decisions regarding the team and setting our goals, as well as guide new team members with their expertise.

The team is composed of two halves working in two different locations: the Watsonville team building our float and the Santa Cruz team building our ROV. This separation allows us to be more accessible to the members, who live across the county, but also includes a new challenge of communication between teams. Using a combination of emails, Discord, GitHub and a Fusion360 team we were able to share files and information quickly, as well as keep up with each other and understand our progress.

The Watsonville team meets weekly on Saturdays from 1 PM to 5 PM, and the Santa Cruz team meets weekly on Sundays from 1 PM to 5 PM. We occasionally have smaller meetings on other days, and closer to our deadlines we would have additional all day meetings. During this time, people work on various tasks solo or in small teams, and no members work on just one part of the ROV. We want every person to experience and work on what they are interested in. The team began with a training period in which all members were given instructions relating to each aspect of making an ROV, including but not limited to CAD with Fusion 360, PVC ROVs, Raspberry Pis, Arduino, Python and camera streaming. This way, each member could experience a breadth of projects to gauge specific interests and focus on what they enjoyed. With the new X Academy Navigator using the Ranger team's ROV from last year, we would be building from scratch. At the start of 2024, we finished the training and began building our new ROV.

RISK MANAGEMENT

At Hephaestus Robotics we want to make sure that our innovative designs function well and won't result in damaged parts, lost money, and wasted time. Whenever parts were being permanently altered or destroyed, a senior member okay-ed the operation. With the testing of the ROV and float in wet environments, we double check connections and penetrators for possible leaks and anything that could damage the device. To protect our members we make sure to always be spatially aware of each other while moving heavy equipment, using possibly dangerous tools, or operating on the edge of a pool.

PLANNING AND SCHEDULING

In July of 2023, leaders and mentors from last year's team met to plan for this season. The leadership team, led by Kai Herbst, developed a schedule to ensure we could develop a new robot and write our planned new ROS software system in time. Following this schedule, team leadership members began each meeting with an announcement updating the team on important events, announcements, and any other relevant information. We would also check in with members individually to help them meet deadlines and find tasks to complete.

Date	Activities
Regional Competition Preparation	
Sunday 12/10	Organize team by individual interests: hardware, software, accounting, etc Layout plan for ROV and float development
Sunday 1/14	ROV, Float, and Topside development starts Course on ROS software starts for Software Team Reviewing of the Competition Manual and Float Manual Design float buoyancy engine
Sunday 1/21	Design ROV frame, electronics in CAD Photogrammetry scripting and planning Design float buoyancy engine
Sunday 1/28	Finish CAD design of ROV Design ROV tool systems Design camera system Continue ROS course Design float electronics and overall design Purchase parts for ROV and float
Sunday 2/4	Begin assembling ROV Assemble ROV electronics Assemble ROV Cameras Begin assembling float Begin ROS control program writing
Sunday 2/11	Continue assembling ROV Assemble ROV electronics Continue assembling float Camera troubleshooting + photogrammetry Continue writing control software
Sunday 2/18	Finish ROS tutorial/course Begin integrating ROS into ROV Start ordering parts and assembling components Plan Technical Documentation
Sunday 3/3	Set up practice pool and begin testing the ROV

Saturday 3/9	ROV can be driven and submerged STEAM Expo - Community outreach, all in attendance / County Fairgrounds Watsonville (Build Your Own ROV activity)
Sunday 3/10	Fundraising Team prep Continue testing ROV ROV buoyancy calculations and assembly Add tools to ROV Begin Topside assembly
Sunday 3/17	Continue Testing ROV Add tool control to ROV Test photogrammetry system Finish camera system Continue topside assembly
Friday 3/29	First draft of tech docs due Prepare for meeting with Congressman Jimmy Panetta
Sunday 3/31	Competition-Ready ROV complete and in the water
Tuesday 4/2	Meeting with congressman Jimmy Panetta about funding ROV team as county program
Sunday 4/7	Continue testing ROV with full setup Begin test runs
Thursday 4/11	Technical Documents Due
Sunday 4/14	Plan engineering presentation
4/7 - 5/4	ROV pool practice and demo run practice Engineering presentation practice
Saturday 5/4	Regional competition
World Championship Preparation	
Sunday 5/12	Review regional scores Start improving ROV, Float, Topside, tech docs, presentations, and other competition components Start planning for World Championships
Thursday 5/16	Santa Cruz COE School Board Presentation
Saturday 5/18	Complete tech docs for submission for worlds
Sunday 5/19	Make final design changes for world competition Finish review of tech docs for worlds
Sunday 5/26	Review engineering presentation for worlds Plan engineering presentation based
Wednesday 6/5	Finalize ROV, Float, and Topside design for World Championships
5/12 - 6/9	Practice runs with ROV demo team Practice engineering presentation
Sunday 6/9	Ship out ROV, Float, Topside to Kingsport, Tennessee
Tuesday 6/18	World Championships

DESIGN RATIONALE

One of our goals for this year was to make an ROV that was highly modular in its shape and systems. We leaned towards design choices that would allow us that flexibility and repairability that modular design had given us in the past.

FRAME

Talos IV's frame is built from sections of 1120 Series GoBilda Aluminum Channel. The channel is assembled in a rectangular prism to allow flexible placement of many peripherals. It also meant we would be able to iterate on the frame very easily. A rectangle of channel that makes the top, with four channel sections running down to another rectangle of channel. Four horizontal translational motors are attached to vertical channels rotated 45 degrees, making a vectored motor design to allow strafing, turning and forward motion. Two vertical motors are attached to the top channel on the left and right sides. The main gripper tool sticks out from the front attached to a second servo controlling yaw.

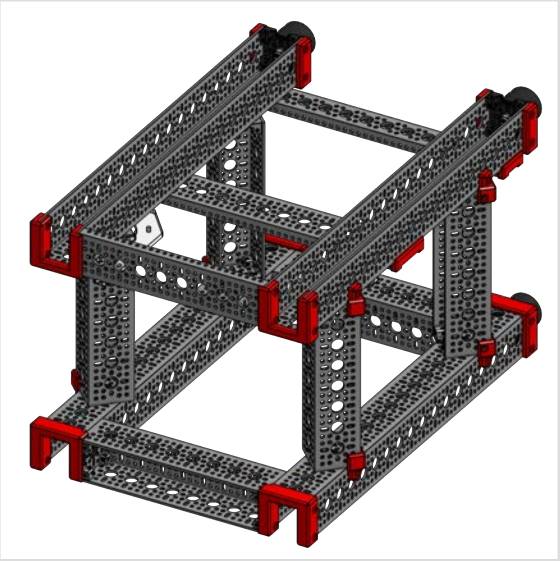

Figure 2: Talos IV frame is a 31cm by 37cm by 41cm cube assembled from Goblida aluminum channel. It supports the two aluminum rectangular enclosures, the six propulsion motors and an array of tools and sensors.
Credit: Bennet Menzer

We continued using the aluminum channel we'd had in the past due to its strength and modularity, which allowed for rapid prototyping, but switched from Actobotics' imperial to GoBuilda's metric measurements. The GoBuilda system uses side tap pattern mounts to attach aluminum channel segments. Pieces can be attached to each other in many different places, similar to Lego blocks. This flexible shape makes it as easy as moving screws to incorporate a different design or move peripherals. Additionally, the reusability of the aluminum channel—as compared to 3D printed or laser cut materials—allows us to remain environmentally conscious while making innovations and providing flexibility for changes. We designed the frame in Fusion 360 before purchasing parts, then were able to easily assemble the full ROV.

The ROV has four polyurethane ‘feet’ on the back so that while out of water, it can be placed on those without resting the ROV on fragile tools on the bottom, namely the gripper and SMART repeater spooling mechanism.

ELECTRONICS ENCLOSURES

he electronics enclosure system for the 2024 MATE ROV competition marks a remarkable cost and design improvement over the previous competition year. The previous ROV (Talos III) electronic enclosure assembly included three four-inch watertight enclosures from BlueRobotics, totaling to $1,204. For this year the team considered three possibilities for the electronics enclosures: continuing with the BlueRobotics enclosures, using premade enclosures, or designing a custom acrylic enclosure.

Option	Cost	Durability	Volume	Cooling	Waterproofing
Blue Robotics Enclosure	High	High	High	Medium	Easy
Custom Acrylic Enclosure	Medium	Medium	Medium	Medium	Difficult
Polycase Enclosure	Low	High	Low	High	Medium

Figure 3: Decision Matrix for Electronics Enclosures

The team determined that using a Commercial Off the Shelf (COTS) waterproof aluminum enclosure from Polycase was the optimal solution for Talos IV’s due to its low cost, low volume, high strength, and passive cooling properties. The two AN-22P junction boxes from Polycase totaled $96.67, representing a 92% cost reduction in the electronics enclosures for Talos IV. The ROV’s electronics are divided into two enclosures: a main electronics enclosure and an ESC enclosure. The dual-enclosure design allows the clutter and heat of the Blue Robotics Electronic Speed Controllers (ESCes) to be separated from the main enclosure, which includes the Raspberry Pi, Ethernet switch, and supporting devices. Additional enclosures are used for the ROV cameras for freedom in mounting location around the ROV frame, thereby adhering to our philosophy of adaptability on the ROV.

Figure 4: ESC Enclosure
Credit: Bennet Menzer

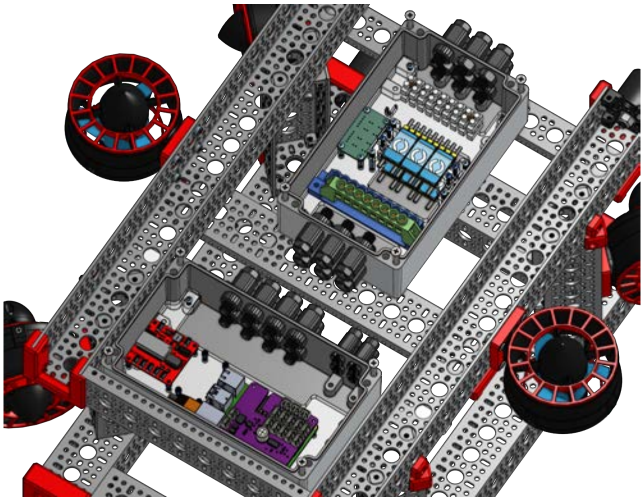

Figure 5: Electronics enclosures mounted on frame.
Credit: Bennet Menzer

ONBOARD ELECTRONICS

Talos IV's onboard electronics consist of two main Polycase enclosures and three additional smaller camera enclosures. The main junction box houses a 12-5V power converter, an SwitchBlox tiny Ethernet switch, and a Raspberry Pi 4B with the second version of our custom made Raspberry Pi Hat. The Pi Hat contains four I2C channels for sensors and distributes 12V power to the Ethernet switch and 5V power to the Raspberry Pi. A PCA9685 chip on the Pi Hat allows the Raspberry Pi to send Pulse Width Modulation (PWM) signals to the motor controllers through an I2C bus. These signals are carried over a ten conductor cable bus to the ESC enclosure and interfaced with the motor controllers using a custom PWM extender board. The Ethernet switch interfaces the tether with the main Raspberry Pi and the remaining Ethernet connections are used for external cameras controlled by Raspberry Pi Zeros.

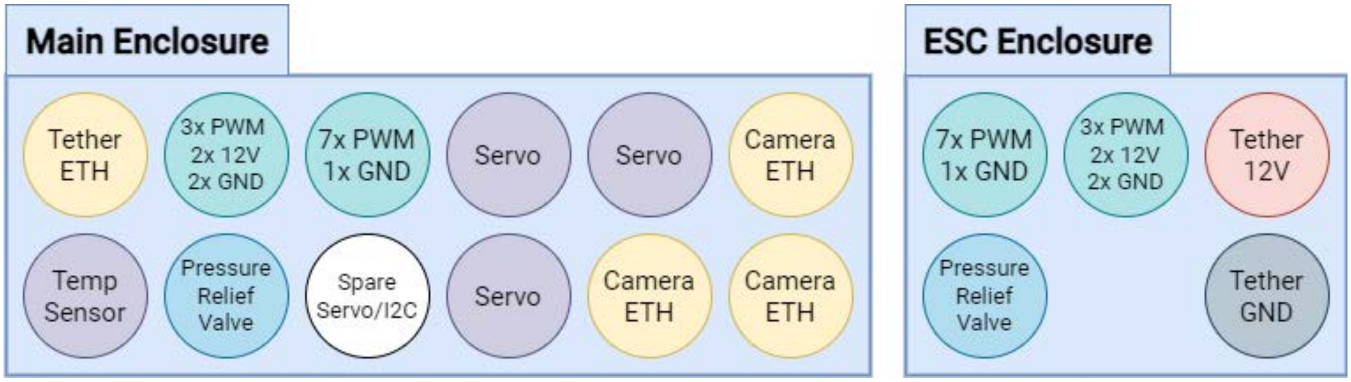

Figure 6: Penetrator Connections
Credit: Bennet Menzer

The main electronics enclosure receives the tether Ethernet connection, while the ESC enclosure receives the power and ground wires, which are interfaced through four twenty-six gauge conductors to the main electronics enclosure, powering the Pi Hat and the supplemental 12V to 5V power supply for the cameras.

The ESC enclosure has a double-stack design of motor controllers to minimize the enclosure volume. There are three motor controllers per level that are connected to eurostyle terminal block connectors to connect with the thrusters. Two large brass terminal blocks provide the 12V power and ground connections. Ferrules were used to shorten the wire connections and expedite terminal block connections.

CUSTOM PCBS

Talos IV includes the following custom made electrical components: a Raspberry Pi Servo Hat, servo connector board, temperature sensor, pressure sensor, leak detector, and camera power supply. All components were designed using KiCad, a free open-source PCB development software.

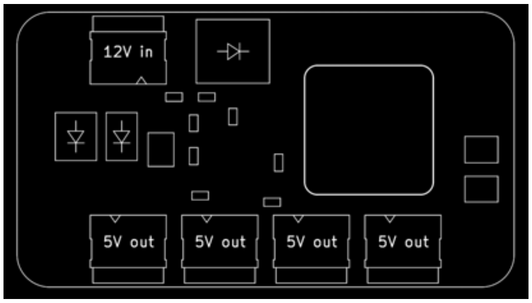

Figure 7: 5V Power Distribution Power
Credit: Bennet Menzer

Our Raspberry Pi Servo Hat simplifies the internal wiring, thus freeing up space inside the main enclosure. The custom board was adapted from the open-source design of the SparkFun Pi Servo HAT. It uses Molex SL connectors and a power delivery system with a single 12V input and 12V and 5V outputs. The power outputs on the board simplify the internal wiring of the ROV by directly powering the Ethernet switch and Raspberry Pi. This eliminates the need for an additional power lead and bulky 12V to USB power convertor. Paired with the Molex SL connectors, the custom Pi Hat minimizes the chance for malfunctions such as connector detachment by streamlining components within the main electronics tube. This enhances the serviceability and repairability of the ROV.

The Servo Connector board was constructed with the use of Molex SL connectors and simplifies the wiring to the ESC's. It directly connects to the Pi Hat. For the temperature sensor, we used the TSYS01 temperature sensor chip to provide high resolution temperature readings. Moreover, the pressure sensor uses the MS5837-02BA chip to provide high resolution pressure readings. To detect possible water leaks in the enclosure, we used an ADC081C021 analog to digital converter chip. The temperature sensor, pressure sensor, and leak detector were connected to the Pi Hat via an I2C bus. Lastly, our camera power supply uses a 12V to 5V down converter with 5V outputs to supply the cameras with power. One problem with modular systems is that they can be overly complex, and our custom PCB design solves that by integrating a complex goal into a few chips.

The main risks associated with custom parts include design flaws, functional errors, and ease of replaceability. To mitigate these issues, the team underwent multiple board iterations. Copies of the custom boards were assembled to use as spare parts.

TOPSIDE CONTROL STATION (TCS)

Figure 8: Topside Control Station
Photo Credit: Kai Herbst

The Topside Control Station (TCS) is housed inside of a waterproof Pelican Storm Case iM2720 which measures 62.48 x 50.04 x 29.72 cm. Inside it are two BeeLink mini PCs running Ubuntu 22.04, one of which is connected to a topside 22” monitor for the pilot to watch live footage from the ROV to maneuver it. It also contains a separate, removable laptop for the scientist, who handles tasks that require analysis of camera feeds. Both computers connect to a WiFi router which is also connected to the tether Ethernet cable. This puts all computers on the same network with the ROV Raspberry Pi so that they can access the camera feeds and send the control signal. Both computers, the monitor, as well as the WiFi router are powered via a power strip located on the bottom of the TCS which receives energy from outside of the case.

The TCS also houses a Logitech X3D joystick connected via USB to the pilot’s PC to control the ROV. The pilot computer takes this information and calculates the desired velocity for each motor and sends the corresponding PWM value to the ROV Raspberry Pi. The Raspberry Pi runs each channel on the Servo Hat at its given value. The ESCs receive this signal and deliver the necessary power to the motors.

We choose to use multiple computers in our TCS so that the scientist can have a large amount of control over what they are doing on their computer without distracting the pilot, who also has a dedicated computer. By using a Wifi design over just a single computer, we can easily connect the ROV to additional computers if needed, or even stream it directly to the internet for the very remote viewing and operation.

SOFTWARE

The software for the controls on the ROV uses the Robot Operating System (ROS) application programming interface (API) for Python. We chose Python because it is easy to learn and is compatible with numerous well-documented packages relevant to our project. Many of the electronics we utilized came with Python code already available to test the parts. We chose to use ROS to control the Talos IV because it provides an efficient and streamlined way to control the ROV. Specifically, we used the Humble Hawksbill distribution of ROS2, because it has long-term support, it is easy to use, and it is powerful enough to accomplish handling the controls of the ROV.

Our system works by using ROS nodes, which are Python scripts that can communicate with each other using the ROS framework. A talker node running on the topside computer outputs a list containing all of the inputs from the joystick controller. Through ROS's Dynamic Discovery feature, devices on the same subnet can access each other's nodes. Therefore, a listener node running on the ROV's Raspberry Pi 4 is able to take in the joystick inputs from the topside. We then run those inputs through an algorithm that converts the values so they can be output via PWM to the thrusters on the ROV. This system creates a seamless interface between the controller in the pilot's hands, and the thrusters that move the ROV.

Grafana is a software that allows for visualization of data. It displays graphs in real time of the data collected by sensors on the float, like depth, pressure, or temperature. Time-stamped sensor data is written to the time-series database, InfluxDB, which is then uploaded to Grafana and displayed in different visualizations like histograms, bar charts, time series, gauges, and more all at once. It can also display web page data, including multiple camera feeds.

TETHER

Talos IV has a compact tether made up of two 12 gauge wires for power and one Ethernet cable for data. The Ethernet cable contains four twisted pairs, eight total conductors. Two pairs connect the onboard Ethernet switch to the router at the surface, and the Ethernet switch in turn is connected to our main Pi and each Pi Zero in the camera boxes. The other two pairs are unused.

These three cables along with a steel cable for strain relief are wrapped in a plastic flexible sheath, which protects the tether, keeps the cables together, and allows purchase for the tether manager. The steel cable connects to a secure location on the topside and directly to the ROV frame. Sections of pool noodle foam are also applied at intervals and attached by zip ties to the cable to keep the tether high in the water and away from any obstacles on the ground.

Talos IV's tether is managed in a specific way as to not damage the ROV, entangle the ROV, or cause a tripping hazard during operation. Before launching the ROV, the tether is arranged in a coil where it can be easily unwound. Any knots, tangles, or twists must be dealt with before launch. When everything is ready, the ROV is lowered into the water and the tether managers begin to actively manage the tether. The main tether manager maintains an appropriate amount of slack to prevent the tether from getting in the way of operations or holding the ROV back. The assistant tether manager is responsible for ensuring that the tether is coiled neatly, as well as looking out for the main tether manager. To help mitigate entanglements, the pilot will avoid rotating in one direction for too many revolutions.

Penetrators are located on the back-facing side of the front electronics chamber where the tether attaches. This connects with power and information the ROV and the topside station. Detachable connectors are used between the ROV and tether, which allows the ROV and tether to be carried separately and reattached quickly. The TCS has openings where the tether Ethernet enters and attaches to an internal router, which in turn is connected to topside computers.

PROPULSION

Talos IV uses six Blue Robotics T200 thrusters for propulsion. Two vertical thrusters control heave and four horizontal thrusters in a vectored configuration provide surge, sway, and yaw. We cannot run the T200s at their maximum speed otherwise we would use more power than allowed for the Ranger class. These are the calculations:

31.21A * 20V * 6 thrusters = 3745.2W > 300W.

We instead run the motors at 12V and the motor software limits the speed of the motors so they cannot draw more than 2.5A. To determine this speed, we used data from the Blue Robotics that shows the current draw for varying voltages and PWM signals.

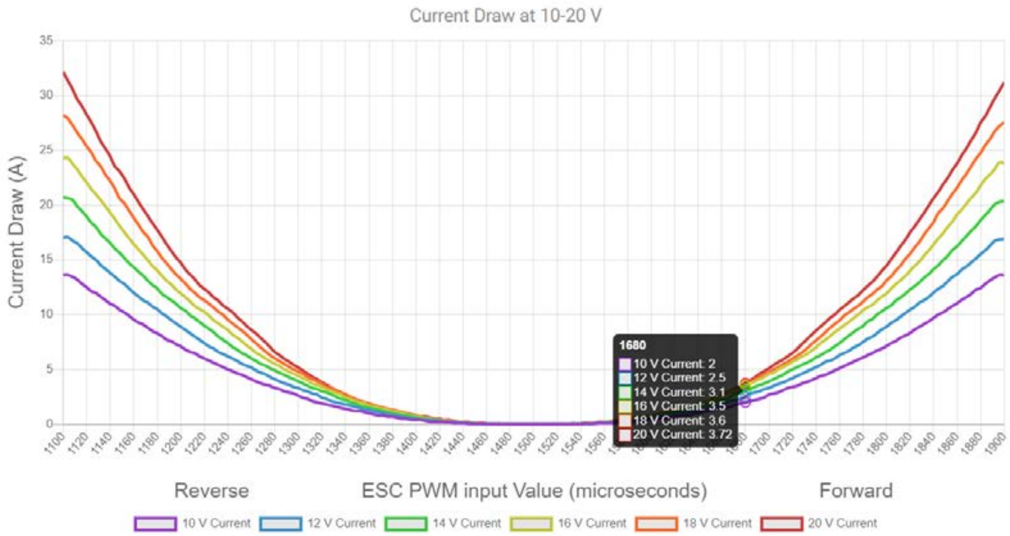

Figure 9: Blue Robotics T200 Power Consumption by PWM and Voltage
Credit: Blue Robotics

When running the motors at 12V, PWM values between 1320 microseconds and 1680 microseconds draw less than 2.5A. Blue Robotics data also shows that with these values, the motors output 10.59 Newtons when running forwards and 8.53 Newtons when running backwards.

The lateral motors are mounted diagonally on the ROV, enabling a vectored control scheme, providing four degrees of freedom rather than the typical three. This enhanced maneuverability allows for precise side-to-side movements, making it easier to position the gripper to align with objects

We purchased six new BlueRobotics T200 thrusters, as with the new Navigator team using our old ROV we had no spares. Other thruster options were T100 motors, with less power draw but no longer sold, or bilge pump motors, which are much cheaper but harder to mount, less power efficient and weaker. T200s were the rational choice given that they performed well on previous models and had high performance.

BUOYANCY AND BALLAST

The majority of Talos IV's buoyancy comes from foam. The foam located on the top of the ROV so that the center of buoyancy is above the center of mass, ensuring that the ROV is stable in the water. With the help of a model of the ROV in CAD, the volume and mass can be calculated quickly and used to solve for the ROV's buoyancy.

PAYLOAD AND TOOLS

TOOLS

Talos IV has two grippers, one horizontal on the front, and one facing down in the direct middle. Both grippers were chosen to contain circle-shaped claws with a rectangle bit at the end with grooves to help grab smaller objects, and the circle will contain small strips of foam to help grip PVC pipes and similar larger objects with some friction and force. The bottom gripper will have a slightly bigger diameter of the claw circle to match the given measurements of objects that claw will be interacting with, based on the request for proposal.

We also have a custom 3D printed spool tool which can hold a larger spool to deploy a SMART cable from the ROV. Without this, it would be very difficult to place the repeater in the required location while running the cable through all the waypoints in the correct order.

BUILD VS BUY AND REUSE

At the end of the 2023 season, we donated our previous ROV, Talos III, and its topside components to our new Navigator team to help kickstart their first robotics experience. As a result, we proceeded to design and build our current ROV, the Talos IV, and its respective components completely from scratch. In making these choices, we had to consider the time we had and the specific requirements we wanted from our parts and the overall benefits of building versus buying.

BUILD VS BUY

Because our Maker Space includes a large amount of robust tools, including an Ultimaker 3D printer and a Full Spectrum Laser Cutter, we were able to build much of the ROV and its systems quickly. The speed enabled effective iterative design.

For the spool for deploying the smart cable, we decided to 3D print a mount for an old 3D printer filament spool because of the low cost to make it as well as the lack of a third party part.

We decided to make custom PCBs instead of buying them because of the control over their function that they provide us. This increased control and compact design reduces the clutter in the electronics enclosures, and facilitates repair of the ROV in case of failure.

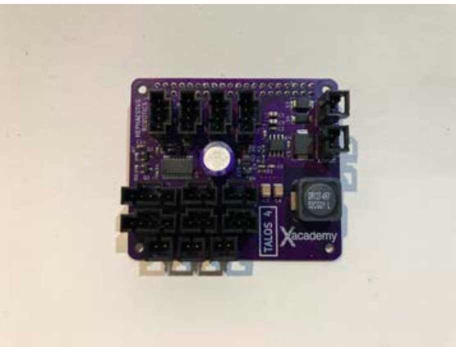

Figure 11: Custom Power Distribution PCB
Photo Credit: Kai Herbst

This year, our float Vulcan III was constructed with new parts. Everything was bought except for the end caps and the buoyancy engine. We designed the end caps in Fusion 360 and laser cut them from acrylic. As for the buoyancy engine, we used parts such as pumps, motors, tubes and bladders to construct the system.

Aside from the buoyancy engine and the plates inside the float, nearly everything else is new. The acrylic tube and sensors were bought from BlueRobotics and the Raspberry Pi is reused. The Raspberry Pi controls the buoyancy engine and sensors.

REUSE

Given our position to design and build our ROV completely from scratch, all parts are new. Although this required more time to prototype and ensure components met our requirements, this gave us more room to fine tune and perfect both our hardware and software.

SYSTEM INTEGRATION DIAGRAM

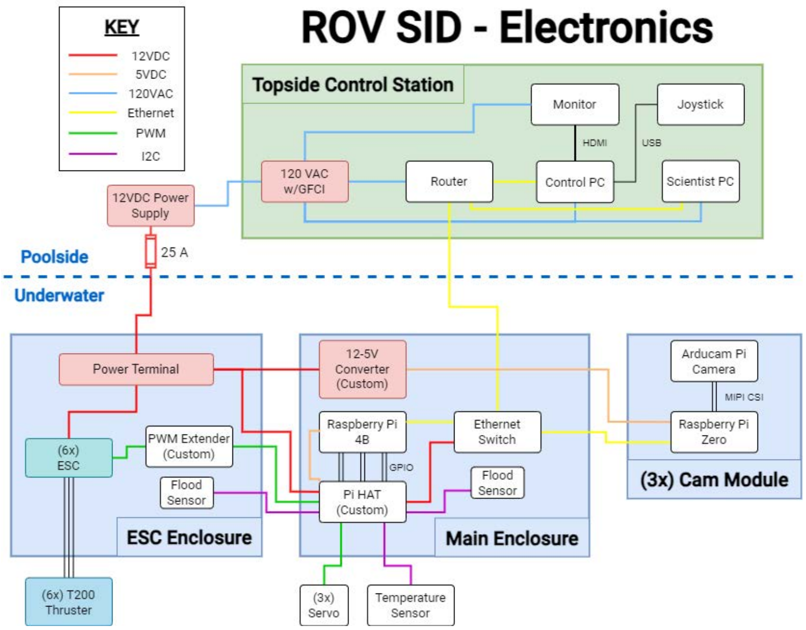

Figure 12: ROV System Integration Diagram

Component	Quantity	Amperage	Voltage	Wattage
Raspberry Pi 4B + Pi HAT	1	3A	5V	15.0 W
Raspberry Pi Zero	3	3.6A (1.2A each)	5V	18.0 W
ArduCam Camera	3	750mA (250mA each)	3.3V	2.48 W
SwitchBlox Ethernet Switch	1	40mA	12V	0.480 W
BlueRobotics ESC	6	15A (2.5A each, limited in software)	12V	180.0 W
Standard Size Servo	3	3A (1A each)	5V	15.0 W
Temperature Sensor	1	1mA	3.3V	0.0033 W
Pressure Sensor	1	1mA	3.3V	0.0033 W
Flood Sensor	2	1mA	3.3V	0.0066 W
Maximum Power (W)				231.0 W
Maximum Current (A) @ 12 V		231 W/ 12 V = 19.3 A		
Maximum (A) with 150% Safety Factor		19.3 × 150% = 29.0 A		
Fuse Used: 25 A				

Figure 13: Fuse Calculation

SAFETY

As a company, we have the responsibility to keep everyone safe. Measures have been taken to ensure the safety of everyone working on the construction of the ROV, as well as anyone who operates, handles, or interacts with the ROV.

Ear plugs are provided while activities with a high noise level are being carried out. Latex gloves are required to handle any hazardous chemicals, such as acrylic glue and PVC cement. Team members are given instruction by mentors on operating power tools before they are used. A safety supervisor is required when team members cut materials or do activities with a risk of injury. Spark-shielding gloves are required to protect from metal sparks while cutting. Safety goggles are required for anyone operating power tools or doing any activity that could create airborne debris.

When using the laser cutter, it is mandatory that a knowledgeable adult operator is present to assist. The laser cutter must be watched the whole time when the laser is running, in case the laser lights the material on fire. In the case of a fire, or any other fault, the laser cutter has a large red button to shutdown the whole machine. A CO2 fire extinguisher is placed next to the laser cutter to put out electrical fires without damaging equipment. A fume extractor with a HEPA filter is attached to the laser cutter to absorb fumes from cutting materials like wood and acrylic.

CRITICAL ANALYSIS

TESTING AND TROUBLESHOOTING

The float team found that through testing our depth sensor, pressure sensor and temperature sensor, the system was inaccurate. The system would get measurements between instruments, and we fixed these issues by modifying the software provided by the vendor.

Previous experience showed us how important it is to model our designs in CAD before building them. We saved time and materials by making CAD models of our ROV and float parts first and then printing or assembling them. We also tested our thrusters, cameras, electronics, buoyancy engine, and complete systems on land before testing in our above-ground pool. This method allowed efficient iterative design and fast development of the new systems.

One valuable lesson we learned from two years ago during the design of Talos II was about dimensions and the usage of CAD tools for design. One thing we made via CAD modeling was the base of the electronics box; we originally intended for it to be made of 1⁄4 inch acrylic but we realized it would be too weak and were able to change it to ½ inch acrylic before printing. Another problem we encountered was that the base was then too large to fit in the frame in its 1⁄2 inch form, so we needed it to be made smaller. Had the complete ROV been designed electronically, this issue would have been avoided. That combined with other avoidable problems resulted in an overly complex design that ended up flooded at our product demonstration that year.

This year, we wanted to get a better feel for the required tasks before building the ROV. We simulated the ROV interacting with the props by using human actors who performed the tasks with our props as the ROV would. This was good for particularly complex requirements of our ROV, like the deployment of the SMART cable through specific waypoints, and helped us create a successful tool design.

For most of our previous years we used three cylindrical acrylic tubes from Blue Robotics to hold our electronics. This year we decided to use waterproof plastic and aluminum enclosures, which allowed for better passive cooling and more efficient placement of electronics in the rectangular space. Using a drill press with proper safety precautions we created holes in the enclosures and were able to use the same Blue Robotics WetLink penetrators we had in the past. This new design was cheaper, less positively buoyant, and easier to attach to the ROV frame.

Aluminum cases for the main and ESC electronics enclosures allow for quick passive cooling, while transparent plastic cases allow for cameras to see the ROVs surroundings.

Being new to ROS this year, we tested it working with just one Blue Robotics T200 Thruster before testing the software on the complete ROV. We connected a Linux PC to a Raspberry Pi over Ethernet, then connected that to a PWM monitor, then to an ESC and a T200 Thruster. With this, we effectively simulated the final ROV and developed a control system that worked immediately once connected to the ROV.

Because we went through a series of refinements and iterations on the ROV design as well as our tools, it was essential that we developed a rigorous testing protocol to evaluate our progress. Testing allowed us to have immediate feedback on our design changes and highlighted areas that needed to be improved, or validated that we were on the right path. Testing became critical when we transitioned from the bench to the pool. For our main enclosures we performed a vacuum test using a hand vacuum pump to 12 psi and waited 15 minutes to ensure it held the pressure. We did a dunk test in a water-filled 50-gallon trash bin to ensure we had proper watertight sealing. Once we knew it was watertight, the team performed numerous simulations of the RFP tasks in a swimming pool.

Lastly, in terms of props, we constructed many props in order to test the ROV that we are constructing. These will be utilized in conjunction with the pool we have adjacent to the Maker Space. This year we purchased three Intex 18′ x 9′ x 52″ above ground pools from an auction site for just $450. One pool is at our Maker Space in Santa Cruz, one pool is at our location in Watsonville and the third pool is a spare.

FUTURE IMPROVEMENTS

- We would like to include a more advanced suite of autopilot and autonomous control features such as depth hold to add greater ease of use for the pilot.
- We would also like to build an arm with multiple angular degrees of freedom which would give the pilot more control over underwater manipulation.
- We would like to experiment with hydraulics to control ROV tools, which could make them stronger and more effective.
- We want to look into more electronic enclosure designs and compact the ESCs and main Pi into one case to simplify wiring and make working with it easier.
- We want to simplify wiring in the float and generally organize its internals better to make working with it easier.

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Underwater cover image: Photo by Ali Abdul Rahman on Unsplash

ACCOUNTING

This year, Hephaestus Robotics' primary income source was a $50,000 grant from the Santa Cruz County Office of Education, supplemented by sponsorships and private donations. However, the Ranger team only received $10,000 of the grant because we needed to allocate most of the money to maintain our maker space and we had to share the grant with X Academy's Navigator team.

Building on the lessons learned from last year's accounting issues, we proactively allocated personnel to focus on finance as the team grew significantly this year. We established a system to better track our finances.

With the establishment of X Academy's Navigator team this year, we donated last year's ROV to them and started from scratch. Since we would purchase all new materials, the CFO examined previous years' spending and developed a budget with some cushioning to account for unforeseen expenses. The CFO tracked expenditures by having all team members complete weekly request forms for any needed materials and then used these requests to ensure we had all receipts. Our CFO then compiled the costs from all the receipts into a spreadsheet to keep track of expenditures.

BUDGET

Expenses		
Project Summary	**Description**	**Amount**
Income Source		
Grant	Santa Cruz County Office of Education	$10,000.00
Sponsorships	Woodstock Pizza	$120.00
Donations	Parents and Community Members	$1,728.83
Available Income		**$11,768.83**
Project Cost Summary		
Available Income		$11,768.83
Actual Project Cost		$6,574.17
Project Balance		**$5,194.67**

Figure 15: Budget

COST ACCOUNTING

Description	Type	Projected Cost	Actual Cost
ROV Mechanical			
Frame Structure	**Purchased**	$250.00	**$189.67**
Frame Hardware	**Purchased**	$200.00	**$117.83**
ROV Enclosures & Penetrators	**Purchased**	$850.00	**$571.61**
ROV Tools (gripper, etc.)	**Purchased**	$350.00	**$ -**
ROV Electrical			
Thrusters & ESC	**Purchased**	$1,500.00	**$1,416.00**
Tether (Cables, Connectors & Adapters, etc.)	**Purchased**	$200.00	**$209.47**
On-Board Electronics (Pi, Eth Switch, etc.)	**Purchased**	$400.00	**$379.50**
X Academy PCBs	**Purchased**	$120.00	**$292.42**
Camera Systems	**Purchased**	$450.00	**$123.26**
Sensors	**Purchased**	$100.00	**$88.00**
Topside Control Station			
Topside Electronics (Computer, etc.)	**Purchased**	$1,500.00	**$1,408.24**
Topside Control Box	**Purchased**	$350.00	**$369.55**
ROV Controller	**Purchased**	$50.00	**$34.99**
Float			
Sensors	**Purchased**	$150.00	**$130.00**
Cables and Pipes	**Purchased**	$100.00	**$50.00**
3D Printing (filament, etc.)	**Purchased**	$150.00	**$150.00**
Raspberry Pi	**Purchased**	$80.00	**$55.00**
Enclosure	**Purchased**	$550.00	**$500.00**
Mini Pumps	**Purchased**	$50.00	**$15.00**
Props			
pvc, hardware, etc.	**Purchased**	$250.00	**$109.62**
MATE Fees			
MATE Entry Fee	–	$200.00	**$200.00**
MATE Fluid Power Quiz Fee	–	$25.00	**$25.00**
Total Costs		**$7,875.00**	**$6,435.16**

Figure 16: Cost accounting

ACKNOWLEDGEMENTS

Hephaestus Robotics is where it is now with the support of many generous individuals. Foremost, Hephaestus would like to thank the Santa Cruz County Office of Education for their incredible support of our team. The COE has paid for our rented Santa Cruz 1,600 sq ft Maker Space for us to build our ROV, in addition to providing the Watsonville location free of charge. This generosity is what made the current team possible.

We also want to thank Doug Erickson and Santa Cruz Works, who allowed us to present and browse their gathering of local tech companies and included us in their newsletter. The publicity, practice presenting, and experience are all greatly appreciated.

We also want to thank the following mentors for mentorship and support: Tim Sylvester, Stefano Carpin, Holly Casaletto, Nikunj Goel, Scot Herbst, JD Hillard, Barbara Meister, Qian Williams, Kurt Yeager. Their knowledge and experience enabled us to make creativity reality.

From Left to Right: Stefno Carpin, Tim Sylvester, Kurt Yeager, and Lars Menzer
Not pictured: Barbara Meister and JD Hillard.
Photo Credit: Reynaldo Barrioz

Finally, we would like to thank MATE for hosting and organizing this competition. We want to especially thank Matt Gardener for the endless hours he puts in as the technical director and for organizing the Monterey Regional and World Championship competitions, as well as the many volunteers that give us such a unique and guiding opportunity.

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