EPIMETHEUS

ROVolution

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Abstract

ROVolution is an innovative underwater robotics company headquartered at King Abdullah University of Science and Technology (KAUST) in Thuwal, Saudi Arabia—a global hub for scientific and technological advancements in the Middle East. Specializing in cutting-edge remotely operated vehicles (ROVs), our team of 12 highly skilled engineers and researchers is dedicated to solving real-world problems while delivering open-source innovation to democratize access to marine technology.

Epimetheus, *ROVolution*'s remotely operated vehicle, is engineered to address the demanding challenges outlined in the 2025 MATE RFP. Designed for reliability, versatility, and efficiency, it combines robust construction with modular tooling systems, including rotatable grippers and specialized tooling tailored for tasks such as sample collection, sensor deployment, and pH measurement. The ROV's development involved iterative prototyping, real-world testing, and direct feedback from marine robotics experts, ensuring it meets the highest standards of performance in diverse environments. Prioritizing affordability without compromising quality, *Epimetheus* offers a cost-effective solution for academic, industrial, and environmental applications, making advanced underwater robotics accessible to a broader audience.

Design Rationale

Engineering Design Process

This year, to ensure that the development of *Epimetheus* was as effective as could be from the onset, *ROVolution* adopted a research design cycle to fuel the process. Noting that this was still *ROVolution*'s second year participating in the competition, the team began by conducting extensive research from consulting other companies' technical documentation, online tutorials, competition videos, and other open-source resources to explore possible designs. This initial research period kick-started *ROVolution*'s design cycle. As can be seen, *ROVolution*'s circular design methodology places an emphasis on the fluidity and adaptability of design choices. This was possible as a result of the collaborative environment that was fostered in the company. Moreover, being a team of 12 members, maintaining effective communication was key to receiving and giving constructive feedback that informed next-steps to improve *Epimetheus*. Following this design cycle effectively allowed the creation of *Epimetheus*.

Credits: TKS Design Website
Figure 1: Design Cycle

Mechanical System

The two largest focuses for this year's design were effectiveness and adaptability. The former relied heavily on CAD designing and innovating unique solutions to common problems for previous MATE teams. Understanding these problems required our team to network with various teams across the world to understand the biggest problems concerning common product demonstration tasks and general ROV maneuverability. Effectiveness also involved ensuring that our designs were cost effective limiting resources spent giving us the most "bank for our buck".

The latter involved a signifcant emphasis on modularity. *Epimetheus* design is split into different sections referred to as tooling. Each system of tooling was designed individually by members of the

ROVolution with specific tasks in mind to ensure *Epimetheus* could tackle the product demonstration effectively. The biggest focus this year for systems design was integration. It was vital for *ROVolution* to design modularity on our frame to allow each of the different tooling systems to fall together on the ROV (similar to LEGO blocks). This modularity also allowed us to easily adapt our design without causing massive redesign or changes to pre-cut pieces. The main system designs are explored in further detail below.

Built vs Bought

ROVolution focuses on functionality while reducing costs due to limited access to resources and funding. Additionally, located in the gated community of KAUST, *ROVolution* recognized the difficulty of sourcing materials from abroad, especially when considering the practicality of shipping. Therefore, despite there being commercially available components, *ROVolution* sought to build the majority of the tooling and frame.

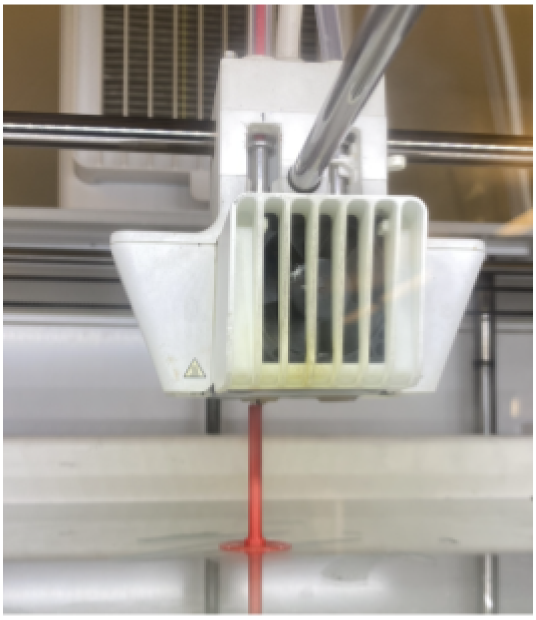
ROVolution also underwent an evaluation process when considering possible materials of the frame. For example, the matrix to the right showcases the trade-offs consulted between various factors such as mission functionality, physical properties, and availability. Moreover, when the end decision was to buy, *ROVolution* explored various companies, as most components would be delivered from the US (e.g. Amazon) and took longer to arrive. Ultimately, when possible, *ROVolution* considered more local options when buying, such as the university's PCL facility, but resorted to AliExpress and Amazon, despite the delivery times, when resources were locally unavailable.

Frame Rigid

Material	Density	Tensile Strength	Stiffness (Young's Modulus)	Corrosion Resistance	Water Absorption	Machinability	Availability and cost (links/places)
Aluminum 6061	2.7 g/cm^3	290 MPa	69 GPa	Excellent Resistance	N/A	Incredibly Machinable, PCL has all the machine	PCL: $26.86 PCL: $47.75
Anodized Aluminum 6061				Increased Resistance as compared to standard Aluminum			N/A
Powder Coated Aluminum 6061				Excellent Resistance			PCL
Carbon Fiber	1.75 - 2.00 g/cm^3	3.53 GPa	230 GPa	Excellent Resistance	Minimal	Low Machinability	435.70 SAR
PEEK	Depends on the type we use. Refer to this	170 MPa	3.6 GPa	Excellent Resistance	Low Absorption	High Machinability	N/A
Stainless Steel	7.5 to 8.0	621 MPa	203 GPa	Decent Resistance given our application	N/A	Generally difficult to machine + PCL may not have parts	PCL
PVC Sheet	1.48 g/cm^3	47 MPa	3.7 GPa	Excellent Resistance	0.4%	Able	PCL: $312.70

Credits: David Dewei Zhang
Figure 2: Matrix showing the trade-offs considered for the materials of the Frame.

The frame is designed with 2 specific materials, High Density Polyethylene (HDPE) and Aluminium. The former we ordered from Aliexpress and used CNC machinery to cut into the specific shape we wanted. The latter we secured through a strategic deal with the university department we have been coordinating with. The Aluminium was cut using a 4000 W laser cutter. We chose these HDPE for our side plates because of the buoyancy capabilities of HDPE as a material that still had a high density. This proved ideal over other plastics and sheets that were less dense and less buoyant. The Aluminium was chosen as it was a stronger material that we had access to thanks to our connection with the university.



Credit: Atisam Faisal
Figure 3: Built components being manufactured on 3D Printer

Additionally, a major part of our built vs bought philosophy is 3d printing. All of our tooling is made with either PLA or Resin-based printers. We used PLA for general prototyping and due to its high affordability. We used resin-based printing for more intricate designs that required higher precision and smoother finishes. One example of a design that required resin based printing is the buoyancy pods that sit atop *Epimetheus* These needed to be the correct size to ensure our ROV would remain buoyant and thus were printed out of resin printers to ensure reliability.

It is important here to highlight *Epimetheus*' tooling, all of which was designed and built by *ROVolution* members. The high focus we place on functionality and innovation is best illustrated by the following innovations which are discussed in greater detail below:

Frame Design

Before designing the frame, we needed to consider the number of thrusters, the tooling, the electronics capsules, and the hydrodynamics of the ROV itself. This meant spending over a month of dedicated CAD designing in which we ran through multiple different iterations of the frame design (with multiple advice sessions from trained experts in the field) to pick one that best fit our needs. In the end we picked a box shaped design with two HDPE plates connected to the sides of two bent sheets of Aluminium leaving the middle of the ROV hollow. This created two levels and a cuboid shape which allowed for modularity and balanced structural integrity. The 3mm aluminium was also bent to increase the stability, tolerance and strength. The only drawback of this material was the heavy which pushed us to focus heavily on buoyancy. To combat this we implemented voronoi pattern cutouts in the aluminum itself, which were inspired by nature to minimize weight whilst maintaining overall structural stability.

Credit: Atisam Faisal
Figure 4: Cardboard Model of ROV

We chose the standard 8 thruster arrangement from ArduSub consisting of 4 vectored and 4 vertical thrusters promoting 6 axis of rotational freedom. This was done to ensure we were not limiting our maneuverability. Furthermore, the 4 vertical thrusters would help provide stabilization and were intended to complement the software PID system ensuring the ROV remained balanced. Our primary choice for thrusters this year is the T200 thruster from Blue Robotics. This is due to the affordable pricing and high thrust capabilities of the T200s. T200s were significantly cheaper at only about $220 compared to other thrusters which sat at prices of around $400. Most of the T200s we gained access to were reused from previous years or borrowed from departments within the university. To ensure proper functionality, and to compare against new T200s, we conducted thrust tests of all 8 of our T200s. The thrust tests allowed us to measure the force outputted by the T200s informing us of their relative strengths to one another. This informed our decisions of T200 configurations and which thrusters to place where.

Once we had configured the T200s and thrust-tested them, we needed to connect them to our frame. We used 2 distinct methods of attachment. The former for the 4 vectored thrusters consisted of simply screwing the thrusters directly onto the Aluminium frame. The frame was designed with this in mind and pre-made holes were made to make space for this. The latter for the 4 vertical thrusters consisted of a custom-designed 3D printed thruster L bracket that connected the thrusters to the frame. The custom-printed L bracket was designed by our engineers to minimize obstruction to other systems whilst reliably holding the T200 in place during testing. The bracket was printed out of resin and bolted onto both the T200 and the frame itself. Thruster shrouds were also printed using PLA filament. This year we drew inspiration from thruster shrouds created by the University of Washington adapting their design to fit the current safety requirements required by MATE.

Credit: Blue Robotics
Figure 5: 8 Thruster Vector Configuration

Manufacturing

The frame underwent multiple prototyping phases to ensure everything fit perfectly before final cuts were made. This was vital primarily due to the shortage of material. As we had limited capital, we only had the leisure of cutting our frame pieces once and so they had to be perfect. Our prototyping consisted of models being made out of cardboard, acrylic, and even foam. This was all vital in ensuring the pieces that fit together in the CAD software would fit together on an actual piece. Additionally, testing was done on the CNC and Laser Cutter being used to ensure that both machines would be operated perfectly for the cuts. Finally, when we believed the design was ready, we began manufacturing and cutting all the parts. Some pieces took longer than others due to unexpected equipment malfunctions and delays due to university projects. This was limiting as the equipment we were using was shared with other university departments who also had hard deadlines to meet. Eventually, however, through communication and compromise, we were able to cut and put together all of our pieces for the frame.

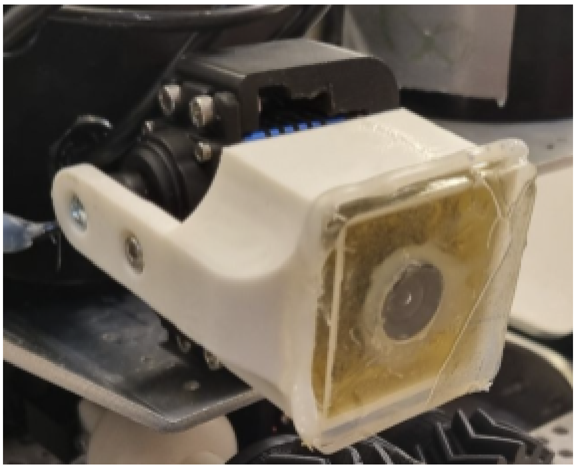
Credit: Atisam Faisal
Figure 6: HDPE Prototype

Buoyancy and Ballast

Buoyancy and Ballast are key considerations taken into account for *Epimetheus* this year. The key difference this year for *Epimetheus*' buoyancy and the buoyancy of other ROVs is the deliberation of design. From the get go, we were aware that our ROV would likely be negatively buoyant (naturally sink in the pool water). Using Newton's laws of motion and free body diagrams we were able to map out the buoyancy of the ROV and run calculations based on the approximate volume of the ROV with and without tooling on board. The buoyancy was designed and printed using resin based 3D printing to ensure maximum quality and reliability. We have calculated the buoyancy by calculating the total volume of the ROV with CAD and weighing the mass of the ROV in air. Thus, we calculated that we needed around 50N of buoyant force, and with this information, CAD designs were then made of two identical buoyancy pods that would rest atop the ROV and connect directly to the frame. Additionally, we bought HDPE foam and laser cut stainless steel ballast to attach to the ROV for buoyancy adjustment.

Cameras

Epimetheus will feature 4 strategically placed USB cameras to maximise visibility for our pilots and ensure tooling can be operated without difficulty. 2 of the 4 cameras are designated to specific tooling systems whilst 2 general cameras are also used. One camera is housed in the front of the ROV and will act as the camera for the Jellyfish Catcher tooling system. The camera will help the pilot in having a clear visual of the catcher and the lid to ensure the jellyfish is captured in the most humane method possible. Another camera housed towards the back will be used to monitor the Fish Catcher. This camera will also be connected to the buoyancy pods similar to the Fish Catcher itself. This is vital in providing the pilots with the best possible view of the tooling system. The final 2 cameras will act as general overview cameras. One will be situated in the rear of the ROV placed towards the bottom to give pilots an alternative view of the ROV and props in the pool. One will be placed at the front of the ROV with the Gripper in frame. This will act as the main camera allowing pilots to have a wide view of the space ahead of the ROV. Additionally, maintaining the Gripper in frame is vital for ensuring that props can be interacted with reliably.

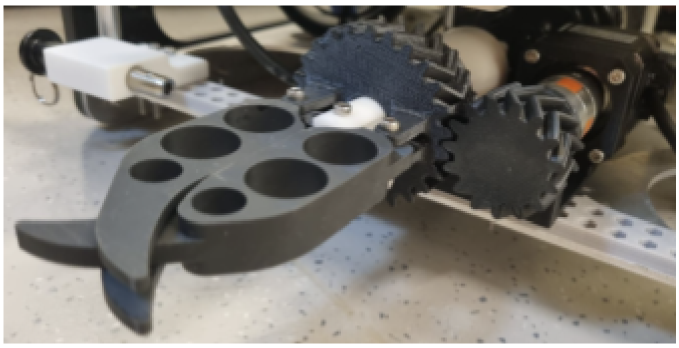


Credit: Konstantin Logashenko
Figure 7: Epoxied Main Camera Mount

Each camera itself is housed in a custom-designed 3D printed casing. The casing is essentially a box with an acrylic lens placed on one side. The camera is placed inside this box, space is made for the camera wire to run out, and then the box is filled with marine-grade epoxy. This waterproofs the cameras which will be exposed underwater. The epoxied cameras in their casing are then much easier to attach to different parts of Epimetheus with modular holes developed for M3 bolts to attach to custom-designed, and printed, camera stands. The stands connect these camera frames to the frame of the ROV holding them securely in place during product demonstrations.

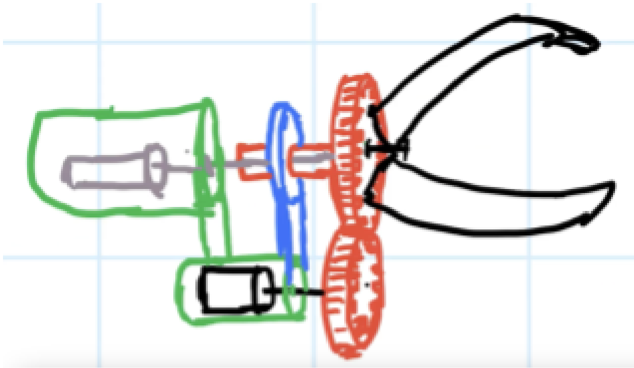
Gripper

ROVolution's current model of *Tenacity* has been under development for a year now, taking into account the lessons learned from last year's competition. This time, the model consists of a completely new mechanism, incorporating both a linear actuator and a stepper motor to aid *Tenacity*'s main movements. Ultimately, in comparison to other gripper models such as from Blue Robotics, *Tenacity* design proved to be a better alternative in terms of its cost and functionality, as it only comprises of commercialized items such as an IP68 linear actuator, IP68 stepper motor, and a silicone boot, but achieves rotation and gripping. This was especially helpful for our mission tasks which required many but was slightly heavier and larger than commercial grippers such as the Newton Subsea Gripper, an alternative choice. *Tenacity* was more modular and the pieces were easily replaced with other bolted components. Additionally, we only implemented two degrees of freedom, rotation and grabbing, as we believed that the 8 motor configuration would account for the missing gripper movements.

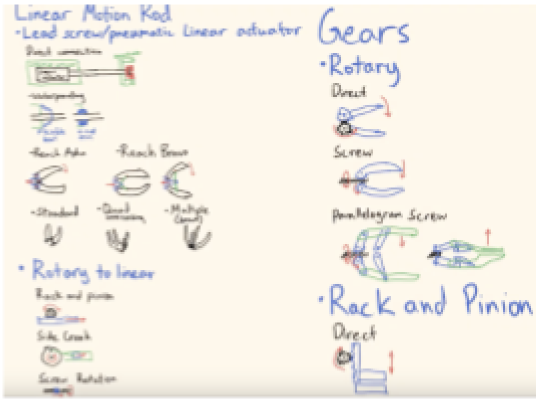


Credit: Stanislaus D'souza
Figure 8: Gripper Attached to Epimetheus Frame

Our first dilemma was designing a gripper that was rotatable. Typical industrial grabber arms use slip rings in order to rotate a linear actuator without twisting the wires. However, because our grabber arm is functioning underwater, typical slip rings have wires exposed to the environment which would be dangerous and risk corrosion and unreliability while expensive waterproof slip rings are extremely heavy and expensive. Thus, after three months of brainstorming and research into mechanical solutions we had an epiphany of splitting the movement into two axes instead of one. The first axis of movement was for the linear motion that would push and pull the shared center of the gripper, rotating them so that they open and close. For this movement, we used an IP68 linear actuator. After looking at many motions for opening and closing such as using rack and pinion, side cranks, screwing mechanism, and gears, we decided that a linear actuator was the most simple and effective method. Despite being already waterproof, we decided to waterproof it with a 3D printed resin compartment and a boot that will stretch with the extension of the linear actuator. This enhancement provides redundant protection for the core drive system while resolving mounting instability in the linear actuator. Originally constrained by a two-point mounting system (one bolt on the drive axle and another on the housing), the actuator was prone to rotational slippage. The added structural support prevents misalignment and distributes operational stresses more evenly. Because the axle of the linear actuator can't be rotated with minimal external force, we had to couple it with a rotatable coupler. Initially, we tried making a built-in joint for the rotation, but realized that although it seemed to have low friction, when you applied a linear force the joint gets stuck and the friction prevents the joint from rotating, so we stuck with a resin printed coupler. Finally, because the linear actuator only had two power inputs, it was extremely difficult to control exactly when the gripper had grabbed an item without risking breakage in the linear actuator or the printed parts. Thus, we implemented a 3D-printed TPU compliant mechanism that was extremely stiff, which would allow the software a period of time to react to the increased current draw while protecting all the components and the objects that it is gripping.



Credits: David Dewei Zhang
Figure 9: Sketches of Original Gripper Design

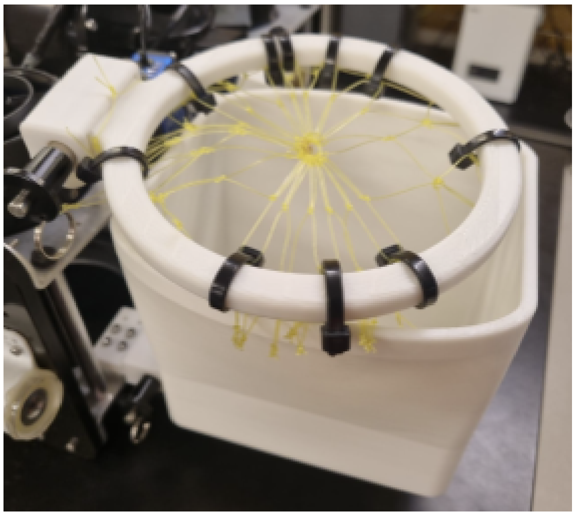


Credits: David Dewei Zhang
Figure 10: Sketches of Possible Gripper Linear Motions

The rotational motion is connected to the claws and the input motion is provided by an IP68 stepper motor offset from the linear motion. We decided to not waterproof the stepper motor because it was an auxiliary movement and we didn't have enough time or the expertise to waterproof a rotating axle without commercialized waterproofing components. Initially, we wanted to use the FOC method paired with a BlueRobotics M200 motor, but it proved to have too little torque to use reliably and efficiently at low RPM. Once the stepper motor is activated, the axle that is coupled to the gears rotate the claws, giving them infinite rotational freedom. The gears had to be redone multiple times. Firstly, we used standard spur gears that were printed out of high accuracy FormLabs resin printers, but somehow they had too much friction and stalled at several areas. After testing, we realized that PLA had a lot less friction than resin, and despite having less accuracy and precision, once we sanded the remaining support off, the gear was very smooth. We then implemented herringbone gears to increase the meshing efficiency and an axle holder that aligns both the axles. This will be extremely important in ensuring the gripper can interact with props that are offset or rotating.

Jelly Fish Catcher

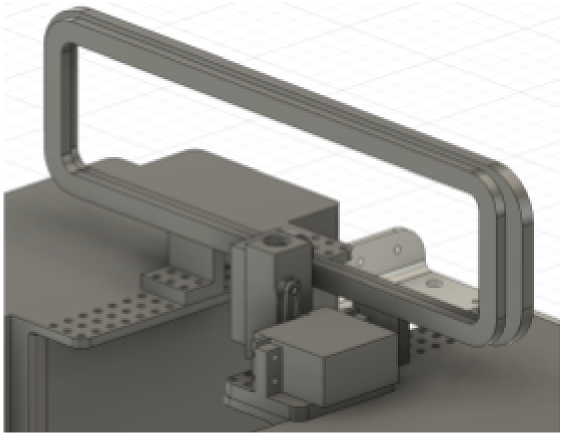
Another important mechanism of *Epimetheus* was the Jelly Fish Catcher, custom-designed by *ROVolution* with an emphasis on safety and modularity. Considering that the mission required *Epimetheus* to capture relatively large jellyfish on the water's surface, *ROVolution* created a solution that delicately ensures minimizing any impact on the jellyfish. This was successfully achieved by a specialized bin with a lid, which is operated by an underwater servo. When activated, the servo will close the lid, which is fitted with a net covering, providing the water flow for the jellyfish's safety. *ROVolution* arrived at this effective and jellyfish-safe design upon iterative prototyping through resin-based and PLA-bases printing. Additionally, to facilitate the removal process, the Jelly Fish Catcher is connected to *Epimetheus* using locking pins; doing so will also preserve *Epimetheus*' maneuverability and balance. Overall, this specialized tool was effective in its task in retrieving the sample without damaging the jellyfish with few open-source alternatives.



Credit: Konstantin Logashenko
Figure 11: JellyFish Catcher attached to Epimetheus

Fish Catcher

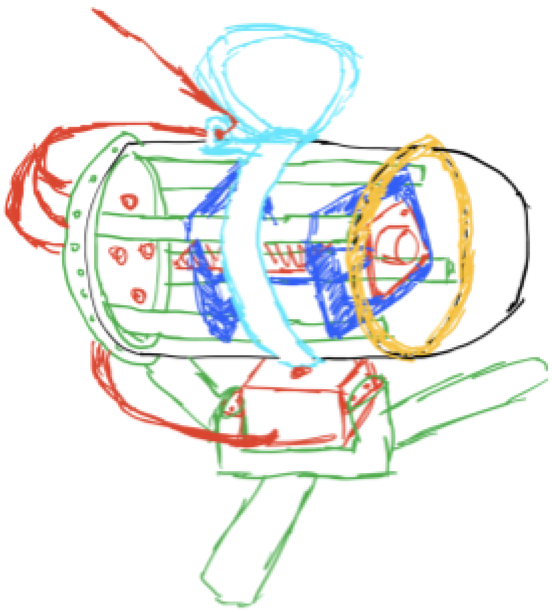
Epimetheus also features the highly modular cost-effective Fish Catcher, mounted atop the ROV in a giant netlike structure. To collect the fish species aggregated underneath the solar panel tray, the Fish Catcher has been designed to catch fish that reside on the surface of the water. In comparison to alternative designs, *ROVolution* modeled the Fish Catcher to be more light-weight and economic while still addressing the needs of the task. Furthermore, this tool is attached to the buoyancy pads of *Epimetheus* using a 3D-printed L bracket, ensuring modularity through a locking pin mechanism. This tool will be used to complete Task 2.2 of this year's competition.



Credit: Dewei David Zhang
Figure 12: Early CAD Model of the Fish Catcher

Photosphere Camera System

One key independent sensor onboard *Epimetheus* is the *Camera Man*. *Epimetheus*' custom-built and printed 360° camera enclosure. The *Camera Man* is designed to capture a 360° photosphere to identify key reference points scattered across the pool. The *Camera Man* is housed atop an underwater servo motor. The servo motor has been specifically chosen for its precise incremental turns allowing for 360 degrees of rotations. Atop the servo lies a custom-designed clamp system that holds the enclosure of the *Camera Man*. The enclosure houses a small microcontroller allowing the PCS to communicate with the pool-side monitor. The *Camera Man* rotates 120 degrees before incrementally stopping to take a photo. Three rotations give the *Camera Man* three photos to send to the pool-side monitor. The monitor then stitches these three photos together giving an overlapping panorama of the entire pool allowing us to easily showcase all 7 required points for this task. Additionally, the *ROVolution* plans on using this to take pictures for a 3rd view of the pool providing a more detailed perspective of the different prompts in the pool.



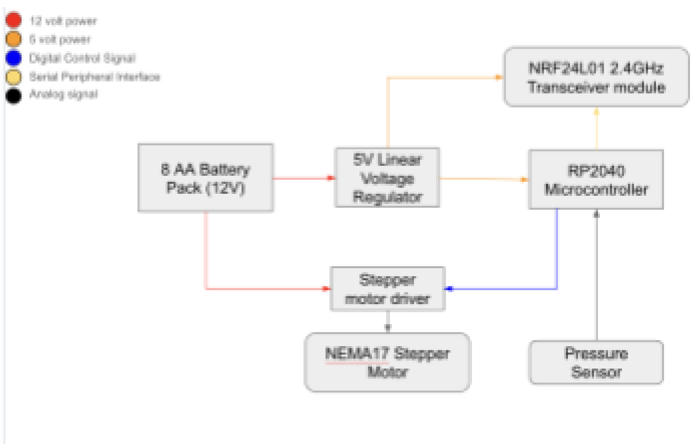
Credits: David Dewei Zhang
Figure 13: Sketch of Photosphere Design

Float

Prometheus, *ROVolution's* current float, was designed to rigorously address the critical failures of its predecessor. The earlier iteration, assembled from scavenged components such as underpowered stepper motors salvaged from decommissioned 3D printers and a makeshift bolt-driven syringe mechanism, was plagued by systemic flaws. Misalignment, frequent motor stalls under minimal load, and compromised waterproofing rendered the system unreliable. Epoxy-sealed syringes and opaque PVC housings further exacerbated maintenance challenges, making diagnostics and repairs nearly impossible. Compounding these issues, a low-cost pressure sensor sourced from Amazon failed outright during testing, exposing the risks of off-the-shelf components in mission-critical roles.

Prometheus comprises a tri-syringe buoyancy engine, paired with a commercial lead screw and high-torque stepper motor. This configuration evenly distributes force across three syringes, eliminating binding and reducing energy loss. To address syringe water flow—a critical bottleneck—the team widened the syringe inlets using a hammer and nail, a method inspired by postage-stamp perforation techniques. This modification, paired with 3D-printed syringe holders, ensured smooth actuation without reliance on unreliable lubricants. Additionally, to increase the alignment and durability, stainless steel structural beams anchor the stepper motor, lead screw, and syringe array, minimizing flex and misalignment. Finally, a universal coupler connects the motor and lead screw, accommodating minor angular deviations without sacrificing torque

Waterproofing, a recurring issue, was resolved through compartmentalization. The transparent PVC, which allowed for safety inspections and simpler testing and troubleshooting, was epoxied to two flanges. On one side, we had a flat laser-cut piece of acrylic that was attached to the syringes with tubing, lead-screw mechanism, and electronics. On the other end, we added a 2.5 cm in diameter pressure relief plug that would release if the buoyancy engine built up too much pressure. The two sides are sead with o-ring face seals so that the entire mechanism could slide out of the capsule to simplify maintenance.

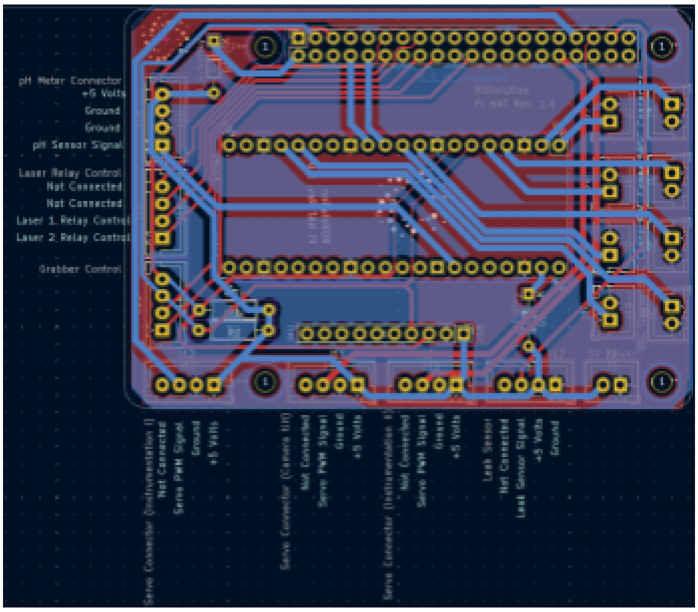


Credit: Konstantin Logashenko
Figure 14: Float SID

During the design process, trade-offs were carefully weighed. For instance, the main mechanism that allowed buoyancy change was facilitated by syringes instead of a pump that blew air into a balloon. The former mechanism was significantly more difficult to implement, but allows PID adjustment for specific depts. Additionally, the lead-screw, high-torque stepper motor, and transparent PVC were more expensive than our initial float last year, but were essential for reliability and functionality. Through our calculations, the float would be significantly positively buoyant and would require significant ballast. However, we decided to continue with a large capsule because it would be easier to maintain, as we could replace individual parts such as syringes, tubes, and the stepper motor without compromising the entire build. Professional ballast was also very expensive, so we decided to use rocks from our surroundings as they were a cheap and functional alternative.

At the core of *Prometheus* lies a Raspberry Pi Pico W microcontroller, which communicates between the stepper motor, pressure sensor, and radio module. Depth data, derived from hydrostatic pressure calculations, is transmitted to a poolside computer via radio. Power is supplied by eight AA batteries (12V total), regulated by a 5A fuse to protect against surges.

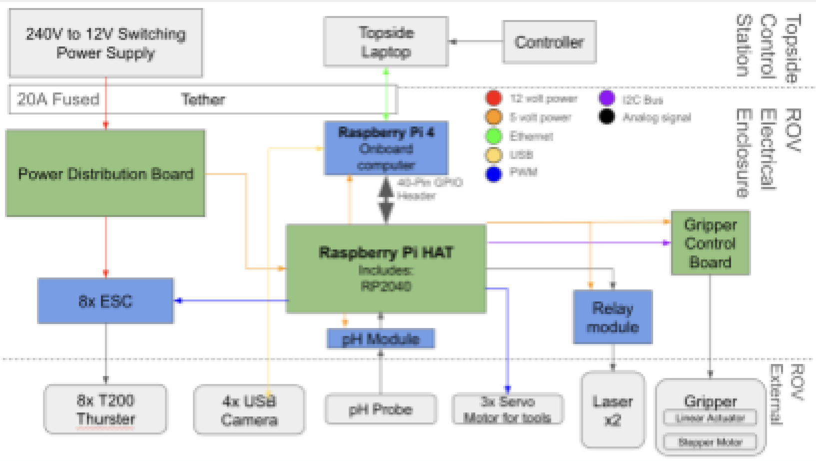
Credits: Konstantin Logashenko
Figure 15: Raspberry Pi HAT Assembled and mounted on Raspberry Pi 4



Credit: Konstantin Logashenko
Figure 16: Raspberry Pi Hat Annotated PCB Design in KiCAD EDA

Hardware System

The primary control system consists of a Raspberry Pi 4 single-board computer and a Raspberry Pi Pico microcontroller board. The latter is mounted on a custom-designed PCB, which allows easy connections to peripheral electronics. This PCB's design is based on the Pi HAT form factor, where a 40-pin two-row header is used for a robust connection to the Raspberry Pi 4 board. The use of this design allows the board to be easily taken off and put back on during development without fear of incorrect connections. The circuitry on this board provides the PWM signals for controlling the thrusters and servo motors, as well as an I2C bus for controlling the gripper via the gripper control board. The RP2040 microcontroller, used as part of the Raspberry Pi Pico development board, is used to run code that must work in real time for thruster control. Its versatile

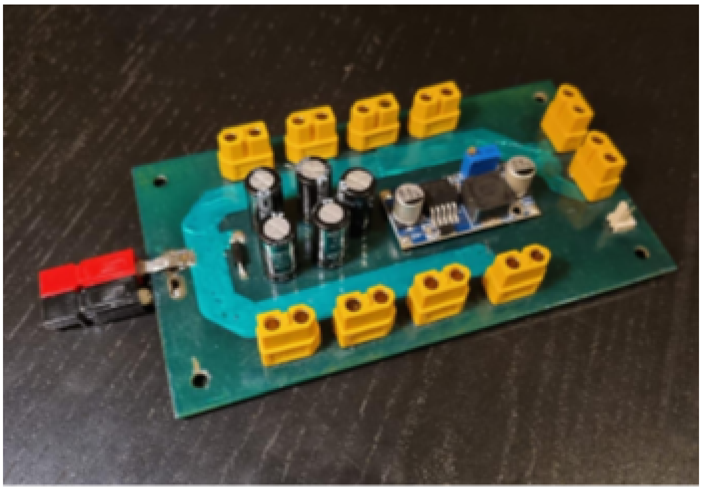


Credit: Konstantin Logashenko
Figure 17: ROV & Tether SID

All peripheral electronics modules are connected to logic PCB through JST8 series connectors, which allows easy assembly and disassembly of the system. JST connectors are widely used for wire-to-board connections, and were chosen for their small size, which allows many connections to fit onto a small PCB. These connectors also cannot be connected with an incorrect polarity, which eliminates errors when assembling or servicing.

Power Distribution

Our ROV uses a custom-designed Power Distribution Board. Its board serves several purposes. Firstly, it serves as the point of connection to the tether power cables. The power board contains a custom-designed circuit to mitigate transient voltage spikes caused by the inductance of the cable. The board also mounts a DC-DC converter module that provides 5 volt power to the logic board and other components. To provide the high current needed for the ESCs, XT60 connectors are used, which are rated to handle 60 ampere continuous load. The use of these connectors allows easy assembly and serviceability, as well as high reliability of ESC power supply. The PCB was designed to handle a theoretical maximum current of 28 amperes with up to 10 ºC increase in temperature of the current-carrying traces, which was calculated according to IPC-2221A standard. To achieve this high current-carrying capacity, a 10 mm wide trace for the positive side is used in conjunction with a ground-plane on the back side. Additionally, the board was manufactured from copper-clad boards with 3 oz/ft^2 thickness of copper layers, which permits low trace resistance, meaning high current carrying capacity with low loss.

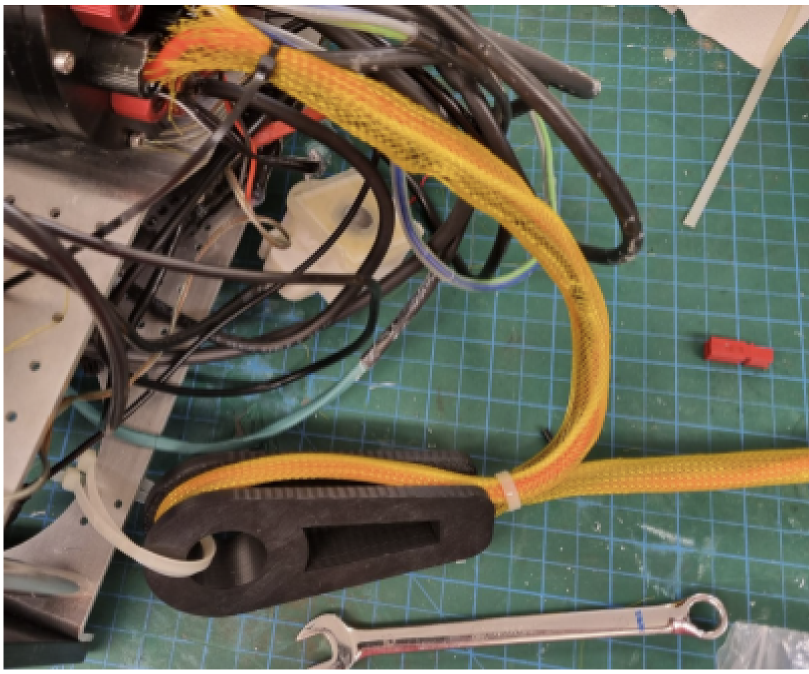


Credits: Konstantin Logashenko
Figure 18: Power Distribution Board Onboard Epimetheus

Tether

Our tether is designed to combine three essential components of any electronic system: power, ground and signal. Power and ground are delivered via two 16 gauge wires and signal from the control monitor to the Raspberry Pi situated inside the enclosure. All tether wires are 15 meters long and combined into a simple tether mesh from a spare SeaMATE triggerfish set. A 25 amp fuse is placed within 30cm of the power supply connection as an overcurrent protection safety measure. We purchased an outdoor waterproof ethernet cable for reliable usage underwater. A CAT7 ethernet cable was chosen to maximise data transmission speeds.

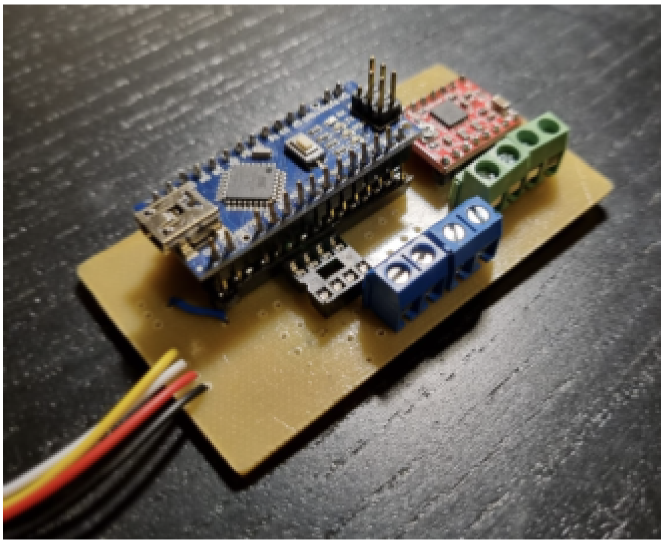
In terms of potting, Epimetheus is a major improvement from last year’s design which attempted to solder a cut half of the ethernet cable on the inside of the enclosure. This was a major safety risk as connections were not solid and could have resulted in short circuiting. This year Epimetheus’s control data is delivered into



Credits: Bobby Dsouza
Figure 19: Tether Connected to ROV via Tether Strain Relief

the enclosure via an ethernet cable with a crimped RJ45 connector enabling a much more solid and reliable connection to deliver data from the surface control computer. This shows the ROVolution's ingenuity in the face of difficulties and obstacles.

Gripper Board



Credits: Konstantin Logashenko
Figure 20: Gripper Board

To control the gripper, a third custom PCB was designed. This PCB consists of a Arduino Nano ATmega328P Microcontroller Board and a Stepper Driver module. This board receives commands via I2C, and creates the electrical signals needed to drive the linear actuator and stepper motor. A separate board was designed for this to allow for iteration on the electrical design of the gripper, which changed several times during the process. Initially, a M200 Underwater BLDC motor was used, however it was later swapped out for an underwater stepper motor to improve performance. Having a separate control board allowed us to perform these adjustments without significant modifications to the main hardware and code, as a single command scheme with I2C communication was used in both designs.

Software System

Software Architecture and System Design

The Epimetheus is controlled by the pilot from a surface computer that communicates with the ROV using a network interface through an Ethernet cable. Both the client (topside) and … The ROV's software infrastructure is built around a tightly integrated stack that balances real-time responsiveness, bandwidth efficiency, and operational intuitiveness. Central to this design is the dynamic camera management system, which addresses the inherent limitations of the Raspberry Pi 4's computational resources. By routing four USB camera feeds through a single hardware-accelerated H.264 encoder, the system minimizes CPU overhead while maintaining 720p resolution at 30 fps. Camera streams are contextually linked to tool operations—activating the gripper, jellyfish catcher or fish catcher automatically prioritizes the associated camera view. This tool-view binding eliminates manual switching delays, ensuring the pilot always receives relevant visual feedback. The encoder leverages v4l2 pipelines to reconfigure inputs on-the-fly during camera switches, achieving sub-50 ms transition times without stream interruptions. This approach reduces bandwidth consumption by 60% compared to simultaneous multi-camera streaming, a critical optimization given the ROV's 100 Mbps Ethernet backbone.

Control Protocol and Thrust Vectoring

A custom UDP-based communication protocol forms the backbone of the ROV's control system, engineered to handle heterogeneous data types with minimal latency. Float values for thruster dynamics, integers for tool actuation, and booleans for system toggles are packaged using typed headers, enabling the surface station to parse commands in under 5 ms. The protocol employs a dual-threaded architecture on the Raspberry Pi 4: a high-priority control thread processes incoming commands, while a telemetry thread reads IMU and leak sensor data, sending it back to the topside computer via the same UDP port. Motor control is delegated to a Raspberry Pi Pico microcontroller running bare-metal firmware, which translates high-level movement directives into precise PWM signals. The Pico's algorithm is designed with the ROV's vectored thrust system in mind, running needed thrusters forward or reverse and varying thrust to achieve desired movement. The algorithm is also designed to keep current consumption below maximum by reducing thrust when several thrusters are running together, which is calculated according to the T200's thrust-current curves. Each camera is connected via USB to the ROV's onboard Raspberry Pi 4 single board computer. The video data is encoded and sent via the ethernet connection to the surface control computer, where it is displayed on a monitor. Limitations of computing power and bandwidth only allow a single camera stream to be active at a time. The pilot may switch between any of the 4 camera streams, which are tied in software to the tool selection. This permits a relevant view for the pilot when they are using a particular tool, and a view of the front of the ROV at other times.

Operator Interface and Adaptive Controls

The pilot interface, developed using Pygame, features context-aware control mapping to streamline operations. Joystick inputs are nonlinearly scaled in precision mode, halving sensitivity for delicate tool manipulation. Analog stick dead zones (6% threshold) are software-compensated to eliminate unintended actuator chatter. The GUI dynamically associates tool activation with camera feeds—for example, engaging the gripper automatically switches to the manipulator camera—while maintaining a live feed of the ROV's frontal view for situational awareness. Telemetry overlays display real-time depth, pitch/roll/yaw, and leak sensor status, with a watchdog timer zeroing thrusters if packet loss exceeds 500 ms.

Safety

Philosophy

Safety at the *ROVolution* isn't about ticking boxes, it's about protecting our ROV, ourselves, and our minds. These three aspects of safety help holistically ensure we are prepared for any working environment and provide us the best chance for success.

Safety is about developing a proactive mindset. Rather than reacting to safety risks as they arrive, we ensure they never develop in the first place. In order to do this we empower our team members with digital and (Alt: university level) on the job university standard safety training to help prevent risks from arising. This proactive mindset carries through to our ROV's frame design with strong materials like aluminum and component-specific safety technology being used. This holistic approach is encompassed with regular mental health awareness checks within our team.

Procedures:

The first procedure in terms of safety, and in joining *ROVolution*'s workspace, is safety courses. In collaboration with the HSE (Health, Safety, and Environment) department of our university, we have designed a safety course that all of our members are mandated to complete before working alongside us in the lab spaces. The course covers key safety features mandated by the university such as but not limited to; appropriate use of PPE (personal protective equipment), appropriate clothing/footwear, and safe operating hours. On top of this, for our unique safety course, *ROVolution* mandates the following from their members; introductory lesson on how to safely handle manufacturing technologies (3D Printers, LaserCutters), how to safely work in a team (key emphasis placed on fostering an open environment), and how to reach out when in trouble (trouble can refer to both technical difficulties and rough patches in life outside of MATE ROV).

On top of our preliminary safety courses, *ROVolution* holds weekly reflection periods for all our members. Unfortunately, in the past month, these reflection periods have been held over chats due to the busy schedules of our members. Nonetheless, these reflection periods allow our team members to get a chance to review the work they've completed over the week and reflect on how they've interacted with different team members.

Another key aspect of our safety procedures here at *ROVolution* is testing pre-checks. We have developed pre-checks that each of our members complete before operating among hazardous tasks. Pre checks are done before operating any machinery (Laser Cutters or 3D Printers), handling electrical components, and manufacturing on the ROV frame. Our submitted JSA sheet explores each of these pre-checks much more rigorously, outlining individual hazards and steps of mitigation. Our operation and safety check sheet can also be found listed below in the appendices.

Vehicle Safety Features:

Safety is close to our hearts at *ROVolution* and has become a huge priority throughout our design process and construction of our ROV. To protect the electrical systems, we incorporated electronic fuses that prevent overcurrent and reduce the risk of component damage or failure. These fuses act as a crucially important safeguard, maintaining the integrity of our power systems during unexpected surges.

We also designed and built our own thruster shrouds in-house, which preserve direct contact with the propellers. The custom solution enhances both operator and environmental safety, especially during transport, deployment, and retrieval of the ROV.

To reduce the risk of injury during handling, all components of the frame and structure feature rounded edges. We have ensured all safety by sanding all sharp surfaces, eliminating all burrs and rough spots that could cause cuts or snags to whomever handles the ROV. We can see an example of this on the black side plates of HDPE, where they are sanded down to be as smooth as possible in order to avoid any injury causing defects.

In terms of electrical systems, numerous steps were taken to ensure the safety of electrical components and of the ROV in an enclosed environment. Fuses are a top priority and have been used in both the ROV and the Float design. Fuses are vital safety measures and ensure that any surges in power are handled away from the ROV and crucial electrical systems. Additionally, soldered connections and JST connectors are used to prevent the use of jumper wires. These cause unnecessary risk and are often too weak to be held together during longer product demonstrations.

Finally, we paid close attention to our hardware by using appropriately sized bolts. This ensures that the ROV stays securely fastened while also avoiding any unnecessary protruding hardware, that might impose a challenge to the construction of the ROV and its functionality. We can see an example of this on the sides of the ROV, as the bolts are specifically sized and chosen to match perfectly and fit in alignment to the desirable lengths.

In essence, safety isn't just a feature of *Epimetheus*, the float, and the tooling systems—it's a fundamental part of their design. By prioritising safety we're not only protecting our operators, we are protecting all of us.

Critical Analysis

Testing methodology:

- ROVolution meticulously tested various components of our ROV throughout the entire building process.
  - Thrusters calibration
    - To increase efficiency when conducting pool tests. Enabled team to edit software
  - After each prototype/component was finalized, multiple intermediate tests were conducted before mounting to ensure that this was appropriate to attach to the ROV.
    - Gripper tested to see if it can hold cylindrical objects as a dry test.
  - We also ensured things ran underwater to determine if any modifications were needed when adapting to the underwater environment.
    - For example testing servo's underwater to confirm capabilities
    - Testing camera frames
  - Conducting dry tests AND wet/pool tests after everything is completed.

Trouble-shooting techniques:

When something goes wrong, we typically follow a procedure to most effectively solve the issue.

1. First of all, since the ROVolution has 12 members, being a lot of members w/ different areas of expertise, when there was a problem, members ensured to ask others (e.g. quick google chat) to see if others could help.

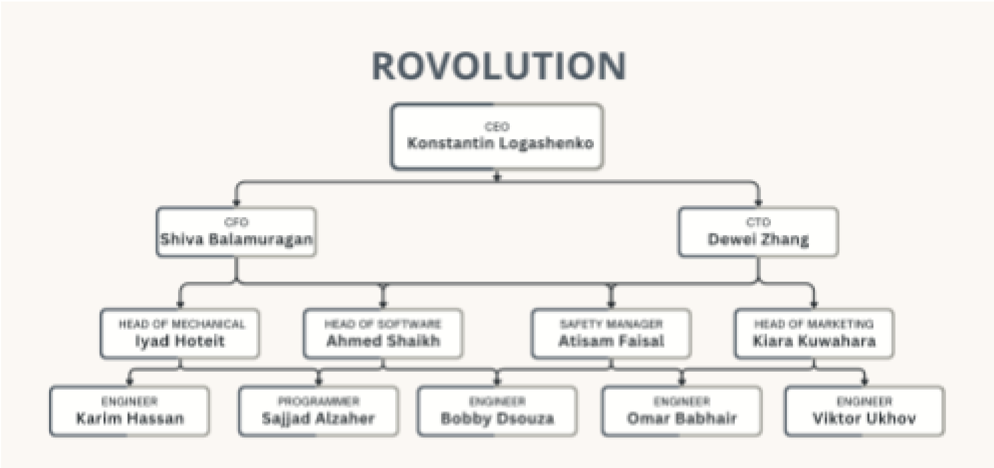
2. Second, members would observe & analyze, and try to consider what issues could be causing.
   - This often leads to further research into a topic.

3. Lastly if something was a problem we had to isolate it from the ROV which took a lot of time but was necessary

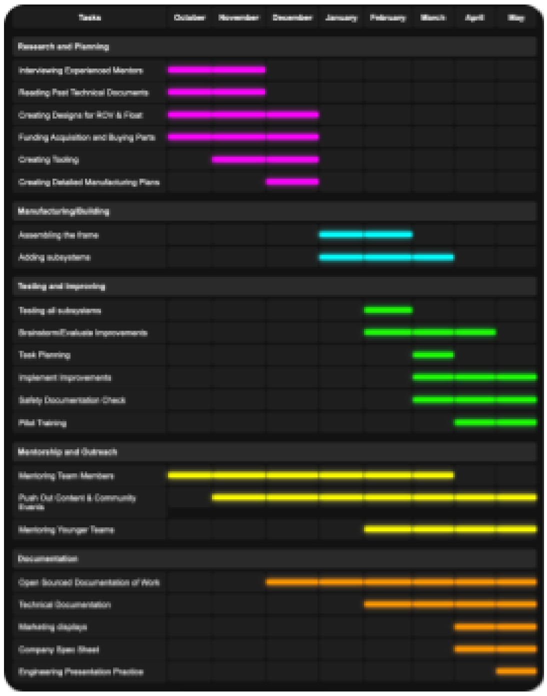
Logistics

Teamwork

As a young company with a growing team of new members, *ROVolution* adopted a dynamic hybrid structure to address early challenges of inefficiency and resource limitations. Initially experimenting with a flatarchy, *ROVolution* members soon recognized the need for clear leadership to streamline workflows, secure mentorship, and prioritize tasks amid constrained funding and equipment. This led to the creation of a hierarchical framework with defined roles—including a CEO, CTO, and CFO, who are in charge of securing funding, assigning tasks to members, and representing the team to administration and sponsors. Eventually, despite having a hierarchical framework, *ROVolution* members realized the need for more job-oriented leaders. As such, *ROVolution* later expanded to include Heads of Mechanical and Software Engineering who are in charge of leading smaller more focused projects towards specific components of tooling or programming. However, to retain the agility and inclusivity of flatarchy, all team members actively contribute to cross-departmental discussions. Leaders facilitate rapid decision-making and accountability, while collaborative forums ensure every voice shapes the project. At the start of the year, weekly brainstorming sessions allowed junior members to propose solutions directly to department heads, merging technical expertise with fresh perspectives while also allowing new members to become more capable.



Credits: Atisam Faisal
Figure 21: ROVolution Company Hierarchy Flowchart



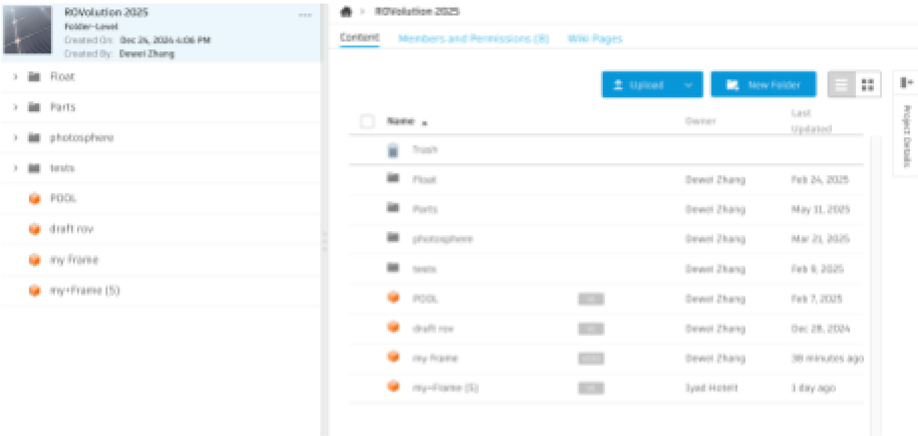
Credits: Dewei Zhang
Figure 22: Company Project Management Timeline

Project management

After reevaluating the shortcomings of the previous year, *ROVolution* leaders set strict deadlines to ensure continuous incremental efforts rather than sporadic last-minute work. The lack of funding and connections with experienced mentorship made it difficult for our work to commence, so the leadership organized an extensive plan to train new members while looking for connections in order to get funding as soon as possible. Our tasks are organized in five categories:

- Researching and planning: due to our lack of experience and connections we need to do … also interviewing process to get new members… while also reading tasks carefully to brainstorm effective solutions
- Manufacturing and building: building is applying our designs
- Testing and improving: due to our experience last year, we need extensive iterative process during design to create viable and reliable solutions
- Mentorship and outreach: represents our marketing efforts and corporate responsibility
- Documentation: open source stuff and complete required documents

As communication is an integral part of efficiency, the team used Google Chats and Instagram to communicate with all members. For specific tasks, there is a document for all members to assign themselves or get assigned tasks (Appendix B). The team used a research design cycle for continuous improvement and iteration. To facilitate this process, *ROVolution* used a shared Autodesk Fusion 360 folder with all CAD files in order for members to design, manufacture, and remodel key things. *ROVolution* also had a Github repository for a combined team journal as well as a mode of documenting work accomplished throughout the week. This helped everyone understand what they have to do and when they have to do it as well as gave everyone an idea of what others in the team were working on.

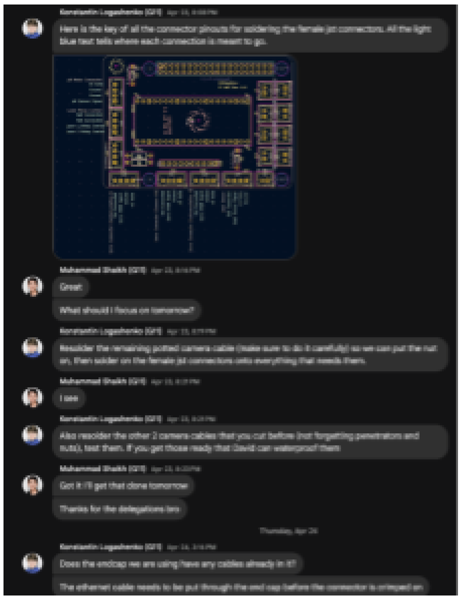


Credits: Kiara Kuwahara
Figure 23: Fusion 360 Shared Drive

Accounting

Developing a projected budget for the *ROVolution* was a key priority for the team, as it established a clear financial framework, which we could use for achieving our goals, while also incorporating contingency planning. As this is our second year participating in the MATE ROV competition, we had some experience on what materials and equipment we would need access to which helped us greatly, however, the bulk of this process focused on brainstorming from all members of the team. The company had created a financial spreadsheet, which listed what purchases need to be made, for what purpose, method of buying, and approximated cost (Appendix D).

With a final approximation of our costs, we then sought advice from experts and funding from KAUST; we set up meetings to seek sponsorships and receive feedback on the components we've chosen to purchase. Through them, we had received lab space and some electrical components, and funding for our project.



Credits: David Dewei Zhang
Figure 24: Google Chat Planning

At this stage, we had created a separation section on our financial spreadsheet; a tracker with all the different items that were donated by KAUST as well as other aspects that were reused from the university. The purpose of this list was to have a clear idea of what was bought, what was reused, and what was donated, to ensure all the financials were in check, but also to report back to our sponsors when justifying the costs we have initially provided them with. Additionally they've provided upwards of 60 hours of supervision and consultation from the KAUST staff, which has proven to be incredibly helpful in the development and fabrication of our ROV.

Overall, we were provided with roughly 4500 USD of funding from KAUST, 4000 USD for our costs, and 500 USD for emergency contingency funds. These funds were then directly transferred to our school WBS account, in which we can access through the help of our teachers to make purchases. Additionally, we received a 500 USD donation from one of the departments from KAUST. In short, we had worked a deal with them, in which we could "borrow" up to 500 USD worth of equipment/material and anything else they needed to get rid of which could help us with our cause. Please refer to Appendix E for further information on the

Our main cost was our 8 thrusters, which were collected from a variety of sources. The first 2 T200s were lent to us from our university partnership with the Coastal Marine Resources (CMR) Core Lab who had a surplus of thrusters. 2 other T200s were taken from a school wide resource of co-curricular expenditures which allowed us to benefit with 2 extra T200s free of cost. The final 4 were bought online and shipped to Saudi Arabia from Blue Robotics in the US. Rigorous thrust tests were then conducted on each of the thrusters using an inverted weight apparatus that measured the force each thruster produced whilst operating at nominal voltage. These thrusts then helped us inform which positions to place which T200s in to ensure maximum balance of propulsion for the ROV.

At this moment in time, the budgeting for the international competition has not been completed yet, hence all of the following will be estimates on our part, and will be subject to changes. Assuming all twelve members can travel and participate in the international competition, all traveling from our home base: Jeddah, our cost comes to roughly 25,000 USD (with reference to what our travelling team had spent last year), including hotels, flights, visas, food, etc.

In conclusion, the *ROVolution* was incredibly thoughtful and effective from a financial standpoint. Thanks to meticulous early planning and proactive sponsorship efforts, we established a clear roadmap for execution and maintained streamlined financial tracking throughout the project, which made this process quite enjoyable and stress free. Additionally the contingency funds of ~ 500 USD proved to be incredibly useful in addressing unforeseen challenges such as damaged electronics upon arrival, incorrect part orders, and accidental component breakages during engineering work.

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Common JST Connector Types – Matt's Tech Pages. www.mattmillman.com/info/crimpconnectors/common-jst-connector-types/.

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Acknowledgements

We would like to take the time to appreciate the following people, organizations, and groups. None of what has been outlined in the above 20 pages or what has been accomplished in the past 7 months would have been possible without your continued support, positivity, and belief in the *ROVolution*. To all of you, from the bottom of our hearts, thank you.

- Prototyping Core Lab (PCL)
    - Rolando Gepolio Jr.
    - Naseem Akhtar
    - Ricardo Excija
    - Meshal Abudlkareem
    - Woodrow Tumulak
    - Mohamed Lotfy
    - Trevor Waldmeyer
    - Athreyan Sundararajan

- KAUST Coral Restoration Initiative (KCRI)
    - Jerry Thomas

- KAUST Coastal and Marine Resources Core Lab (CMR)
    - Andres Espinoza
    - Hatim Abdulbaqi
- Other Individuals
    - Nurzhan Yesmagambet
    - Jiajie Xu

Appendices

Appendix A: Safety Certification for all Team Members

Health, Safety and Environment

CERTIFICATE

OF COMPLETION

Is Presented To

Dewei Zhang

For Attending The

Emergency Incident Preparedness Training (Online)

Held at King Abdullah University of Science and Technology

on June 11th, 2024

Erik Talley

Director of Health, Safety and Environment

Health, Safety and Environment

CERTIFICATE

OF COMPLETION

Is Presented To

Atisam Faisal

For Attending The

Emergency Incident Preparedness Training (Online)

Held at King Abdullah University of Science and Technology

on February 23rd, 2022

Erik Talley

Director of Health, Safety and Environment

Health, Safety and Environment

CERTIFICATE

OF COMPLETION

Is Presented To

Shivahaari Balamuragan

For Attending The

Emergency Incident Preparedness Training (Online)

Held at King Abdullah University of Science and Technology

on June 11th, 2024

Erik Talley

Director of Health, Safety and Environment

Health, Safety and Environment

CERTIFICATE

OF COMPLETION

Is Presented To

Bobby Dsouza

For Attending The

Emergency Incident Preparedness Training (Online)

Held at King Abdullah University of Science and Technology

on June 11th, 2024

Erik Talley

Director of Health, Safety and Environment

Appendix B: "Project Management Doc" Sample Tasks

Float final	☑ Wrap tubing with self sealing silicone tape ☑ Test the tubing	Bobby, David	10th April	Completed
Assembling T200s	☑ Assemble the remaining T200s ☑ Replace nuts with locknuts	Iyad, Karim, Viktor, Omar, David, Kiara	10th April	Completed
Potting everything	☑ Crimping ethernet ☑ Potting: linear actuator, laser, servos, camera wires, power cables, ethernet	Ahmed, David, Konstantin	10th April	Completed
Gripper V3	☑ Assembling and testing new gripper with improvements	David, Konstantin	~~8th April~~ 10th April	Completed
Collecting water sample	☑ Collect water samples ☐ ~~Document it well~~	~~Iyad, David, Ahmed~~, Atisam	~~7th April~~ ~~9th April~~ 10th April	Completed
Finish mounting electronics	☐ ~~Finish mounting electronics~~ ☐ Cut and resolder pH sensor. ~~Pot pH sensor~~ ☐ ~~Crimping Anderson connectors~~ ☐ ~~Potting tether wires~~	Ahmed, Konstantin	~~8th April~~ 10th April	Canceled
Waterproof lasers	☑ Epoxying lasers (hot glue + epoxy + acrylic + 3D printed piece) ☑ Cut the acrylic ☑ Epoxy pH sensor	David, Shiva	~~6th April~~ ~~8th April~~ 10th April	Completed
Assemble Gripper with new parts	☑ UV the new gripper parts ☐ Sand with high grit ☑ Test the gripper	David, Konstantin	~~6th April~~ ~~8th April~~ 9th April	Completed
Mount T200s	☑ Mount 5 T200s with locknuts ☑ Replace all the bolts with lock nuts	Atisam, Kiara, Iyad	8th April	Completed
Continue with potting	☑ Pot remainder of thrusters and second round epoxy solder joints ☑ Pot laser ☑ Pot linear actuator ☐ Pot camera cables + camera enclosures	Iyad, Karim, Omar, Ahmed	8th April	Completed
Finish any incomplete potting	☑ Check epoxy potting quality from Sunday session ☑ Additional potting as necessary ☑ Finish incomplete penetrators	Iyad, Kiara, Sajjad, Bobby, Karim, Viktor	8th April	Completed
Mounting electronics	☑ Lasercut final electronics tray ☑ Mount electronics	Ahmed, Konstantin, Atisam	~~6th April~~ ~~8th April~~ 10th April	Completed

Appendix C: Operations and Safety Check Sheet Sample

Describe Job Step	Potential Hazards	Recommended Risk Control Measures	Responsible Person(s)	Initials of Responsible Person(s)
Setting up Pool Side Station	Heavy Objects Tripping Hazards Moving Objects Slipping Risk	Lifting with proper form and grip (use 2 people if necessary) Each person carrying a heavy object is accompanied by someone to steer clear of obstacles Proper footwear with proper grip to be worn to prevent slipping	Atisam David Shiva Iyad Konstantin Sajjad Omar Viktor Karim Kiara	AF DZ SB IH KL SA OB VU KH KK
Transporting ROV to Pool Side	Dropping ROV Tripping Hazards Slipping Risk Tether Tanglement	Transport ROV with 2 people minimum 1 guider to ensure obstacles are out of the way Proper footwear with proper grip to be worn to prevent slipping Tether manager to hold onto tether at an appropriate distance	Iyad Shiva Viktor	IH SB VU

Appendix D: Expenses Sheet Snippet

☑ era	At PCL?	Item Name	Purpose/Jus	Specifications/Requirements		USD Pric	SAR Pric	S
☑	☐	Screw terminal	function	5PCS, 20A, Line connector	1	1.93	7.24	
☑	☑	58mm o-ring	photosph...	OD 58mm(3pcs), CS 3mm	1		7.94	
☑	☐	Ceramic Bearings	function	6705 25x32x4mm	1		34.43	
☑	☑	Camera capsule PVC	function	55 ID 59 OD	1		4	
☑	☐	Sand paper	function		2		1	
☑	☑	Tether Sheath	function		1			
☑	☑	O ring flange	function	100mm	2	45	168.75	
☑	☑	End cap	function	100 mm diameter, Aluminium, 5x	1	52	195	
☑	☑	End Cap	function	100 mm diameter, Aluminium, 18x	2	30	112.5	
☑	☑	T200	function		6	238	892.5	
☑	☑	Basic ESC	function		6	38	142.5	
☑	☑	Penetrators 8mm	function		5			
☑	☑	Syringe	float	60 ml	3			
☑	☑	Syringe Tubing	float	50cm, OD 13.5mm	1			
☑	☑	Threaded rod	float	1 set horizontal kit, 300 mm	1		39.71	
☑	☑	20 Pin Female Header for Pi Pico	function	Pins: 1x20 pins	1		12.44	
☑	☑	4 Pin JST Male and Female Connector w/ Cable Set of	function	**Length: 20cm** **Pins: 4 pin**	1		11.98	
☑	☑	2 Pin JST Male and Female Connector w/ Cable Set of	function	**Length: 20cm** **Pins: 2 pin**	1		11.71	
☑	☑	Standoff Spacer Aluminum	function	**Size: M6 5PCS** **Length: (L)100mm**	1		33.39	

Appendix E: IFL Donations/Tracker Sheet Snippet

ROVolution IFL 3D-Printing Quota

Item Being Printed	Type of Printer	Type of Filament	Quantity of Material Used
Buoyancy 2	Formlabs 3L Resin Printer	V4 White	406.67 mL
Buoyancy 1	Formlabs 3L Resin Printer	V4 White	406.67 mL
Gear 32 Bit	FormLabs Resin Printer	V4 Black	44 mL
Float Components	FormLabs Resin Printer	V4 White	95 mL
Gripper Version 2.1	FormLabs Resin Printer	V4 White	155 mL
Flange (Float)	FormLabs Resin Printer	V4 Black	59 mL
Gripper Version 2.2	FormLabs Resin Printer	V4 Black	160 mL
Missing Gripper Components	FormLabs Resin Printer	V2 Durable Resin	106 mL
PIP Jellyfish Rod	FormLabs Resin Printer	V4 Grey	15 mL
Linear Actuator Container	FormLabs Resin Printer	V4 Black	144 mL
Waterproof Container Linear Actuator	FormLabs Resin Printer	V4 White	114 mL
Gripper 1	FormLabs Resin Printer	V4 Black	128 mL
Gripper 1.2	FormLabs Resin Printer	V4 White	126 mL
PIP Jellyfish Rod 2	FormLabs Resin Printer	V4 Grey	18 mL
T200 Brackets	FormLabs Resin Printer	V4 White	82 mL
PIP Jellyfish Rod	Ultimakers	Red PLA	8.31 grams
Material Strength Test	Ultimakers	White TPU 95A	45.61 grams
Material Strength Test	Bambu	Basic White PLA	45.61 grams
Gripper Components	Ultimakers	Red PLA	12.66 grams
Float Syringe Holders	Ultimakers	Yellow ABS	68.54 grams
Jellyfish Catcher Rod	Ultimakers	Red PLA	1.14 grams
Float Syringe Holders	Bambu	White ABS	68.54 grams