Technical Documentation

THE KAUST SCHOOL

جامعة الملك عبدالله
للعلوم والتقنية
King Abdullah University of
Science and Technology

Thuwal, Saudi Arabia

Red Sea Robotics Team

Emils Ekers	CEO
Dylan Todorov	CTO
Idhant Nag	Financial Analyst, Outreach
Reuben Potter	Head of Engineering
Nitin Prabhu	CFO, Media Manager
M. Ahsan Jamil	Mechanical Engineer, Editor, SO
Oliver Horvath	Task Tool Specialist
Jacob Kennedy	Float Engineer, Electrical Engineer

Supervisors

Mery Tellez

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Abstract

Red Sea Robotics is a student-based underwater robotics company within The KAUST School. The team will participate for a second time in the MATE ROV competition after a successful first international experience in 2023. Having previous knowledge of our first underwater ROV, Tyrone II, the team will eagerly implement improvements to the new underwater ROV, Tyrone III, a second-generation remotely operated vehicle (ROV) of Tyrone. Red Sea Robotics has carefully selected eight members' roles based on their strengths and interests, allowing the team to work as efficiently as possible. Then, the Tyrone III was made with meticulous planning and attention to detail with improvements in mind. The team has made improvements, emphasizing additions such as Newton Subsea Gripper Gripper Arm, Raspberry Pi Processor, and two new Blue Robotics Thrusters. Furthermore, Tyrone III *has* undergone various prototyping, engineering, and testing to ensure it meets the mission objectives and operates efficiently underwater. This technical documentation thoroughly outlines the evolution of Tyrone III, detailing its process build, justification, safety measures, and financial breakdown.

Red Sea Robotics Team

Reuben, Nitin, Dylan, Jacob, Oliver, Emils, M. Ahsan, Idhant

Project Management

Company Profile

Red Sea Robotics (formerly “TKS Reef Rovers”) is based in Thuwal, Saudi Arabia. This is the second year Red Sea Robotics has participated in the MATE ROV after a successful 2022-2023 year. The company comprises eight members from tenth and eleventh grade who are highly skilled in their respective roles, allowing efficient workflow. The team is structured into different titles, in which it has various aspects, as listed below:

Emils Ekers Chief Executive Officer (CEO)	Oversees operations and decision-making
Dylan Todorov Chief Technological Officer (CTO)	Oversees technological aspect of the Tyrone III
Nitin Prabhu Chief Financial Officer (CFO)	Oversees financial records and seeks sponsors
Reuben Potter Head of Engineering	Oversees engineering aspects of the Tyrone III
Ahsan Jamil Mechanical Engineer	Designs physical ROV components
Dylan Todorov Software Engineer	Develops ROV control systems, software, and debugging
Dylan Todorov, Jacob Kennedy Electrical Engineer	Designs and implements electrical systems for the ROV
Reuben Potter Systems Engineer	Responsible for designing and integrating subsystems in Tyrone III
Jacob Kennedy Float Engineer	Designs and constructs components following mission objectives
Ahsan Jamil Safety Officer	Ensures that ROV is functional within safety requirements
Ahsan Jamil Editor	Writes technical documentation and tracks project management
Nitin Prabhu Marketing Head	Promotes and leads social media marketing

Scheduling and Planning

Figure 1: Red Sea Robotics Project Timeline

The Red Sea Robotics team met twice weekly on Tuesday and Wednesday, dedicating 5 hours weekly to building the Tyrone III at the Coastal and Marine Resources Core Lab (CMR) in KAUST. The editor has made a Gantt Chart upon having a final agreement with the team of how allevents should be met as seen in **Figure 1**. The Gantt Chart is planned ahead of time in terms of deadlines so that the team can get an overview of what to complete within the timeframe and to allow extra time in case an obstacle comes on the way. This ensures that the team meets deadlines and understands what needs to be started and completed by the estimated deadline. Beginning in mid-October, the team worked on frame sketches and prototyping to determine the best fit to align with the MATE ROV regulations. Subsequently, the team continuously met the tasks set by the CEO, who regularly updated the protocols weekly so the team members could adhere to deadlines. The strict deadline will ensure the team will be on track to build the Tyrone III efficiently.

The team communicates through WhatsApp, allowing the team members to be on the same page regarding meeting times and availability. By promptly notifying each other about their other commitments, the team could adjust their plans accordingly and maximize the use of their time in the lab. Additionally, the team utilizes Google Drive to put all the resources in it to ensure all files are in one place and accessible to all team members and mentors. Additionally, the team has reviewed the 2024 mission video and thoroughly discussed with each other what parts should be ordered. Therefore, the team made a shared document part list of what needed to be ordered at the end of December to ensure the build of Tyrone III was stuck to the deadline of Gantt Chart. By January, most Blue Robotics parts had arrived at the lab and were ready to be assembled into the frame, as seen in **Figure 2**.

Figure 2: Parts Delivered

Design Rationale

Engineering Design Rationale

Our process began with prototyping in the early stages to develop the optimal design that aligns with mission objectives, as further discussed in Problem Solving. One of the mission objectives is for the ROV to be under 25 kg, so the team used acrobatics steel frames as they are lightweight and durable. The steel frames were recovered from the previous Tyrone II parts and some of the frame steel was in bad condition meaning that the bolts were loose in the hole. So the team tried to prototype with little as much as frame steel and took out the good condition of frame steel. Additionally, the team also considered where the thrusters should be placed when building the steel frame. The engineers have concluded that having two parallel steel frames and watertight enclosures is best for the stability of the thrusters placed around its perimeter as seen in **Figure 3**. Furthermore, this ensures balanced buoyancy which is discussed further in Buoyancy and Ballast. Then, the engineers screwed the bolts into the frame to join the watertight enclosure.

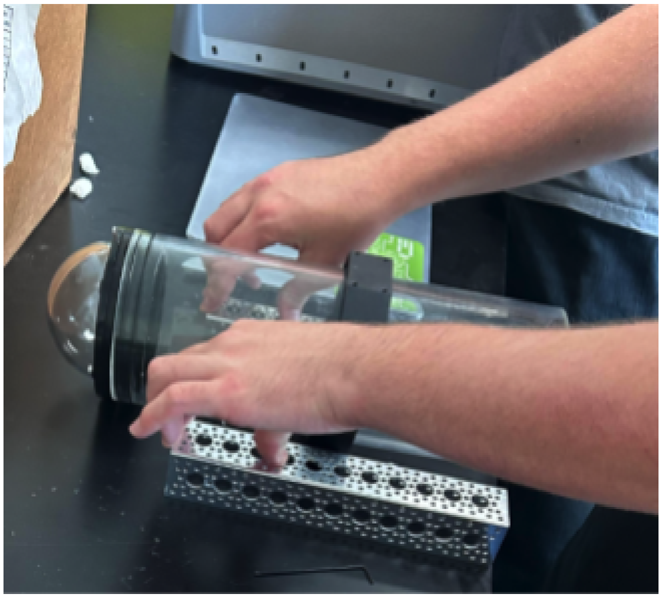


Figure 3: Initial Frame Brainstorming

The mechanical engineer placed the gripper arm holder on top of the small box steel, shown by the red circle in **Figure 4**. By placing this part, Tyrone III can complete mission tasks underwater. For instance, the gripper arm holder will be taken advantage of in Mission Task 1, 2 & 3 where many objects require to be moved around. Additionally, placing it below the watertight enclosure provides an optimal point of view for executing tasks.

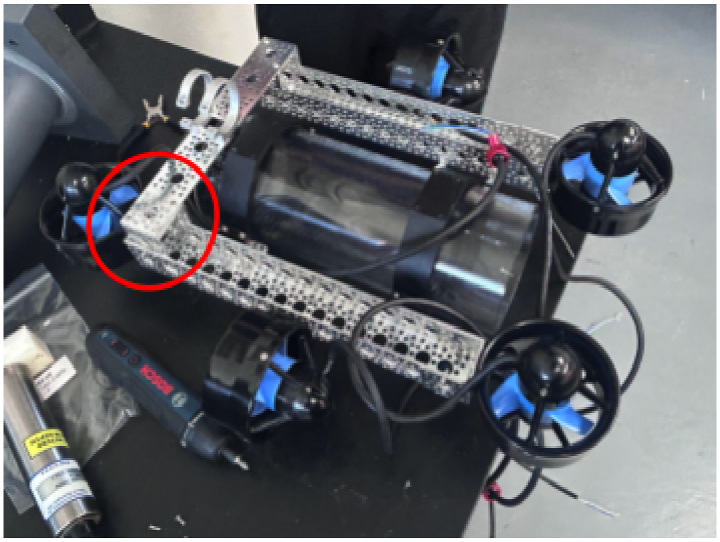


Figure 4: New Addition to *Tyrone II*

However, the small box-like steel was changed into a new design as it would not hold the gripper arm effectively and steadily. Therefore, the engineers installed a longer and wider steel frame in the foundation frame. As a result, the gripper arm now operates with increased reliability and accuracy, meeting the mission objectives with confidence. For instance, the stability of the longer frame steel will be helpful in picking the heavy objects up underwater as it has more torque force.

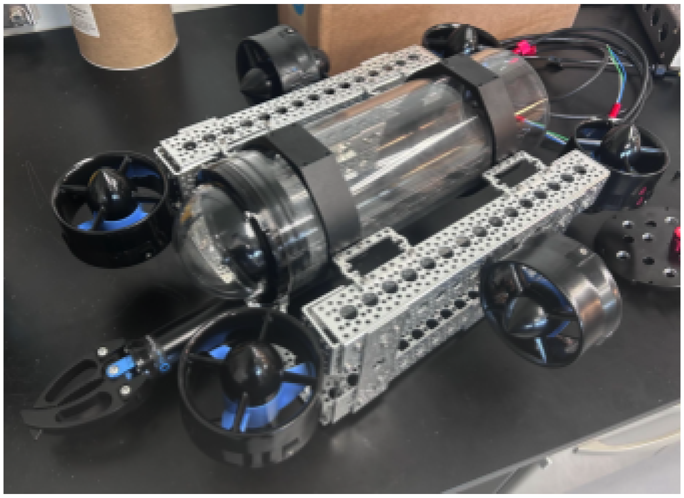


Figure 5: Gripper Arm + Frame Structure

The placement of the gripper's arm below the camera enhances pilot visibility which facilitates seamless underwater control and completing the mission task effectively. For instance, the gripper arm and camera view can be helpful in measuring the props in one of the mission tasks. For example, Task 3 requires extensive use of the camera module in order to observe and manually sketch a graph of the information. In order to maximize the points scored here, it is vital to make sure the quality and positioning of the camera is appropriate. Nonetheless, Red Sea Robotics has made some modifications to the ROV, which include changing the frame to maximize the stability of the gripper arm, changing the capsule penetrator after a failed leak test using vacuum pressure testing, adding the safety guard to minimize the sharp edges on the sides, and lastly troubleshooting the Raspberry PI. The final Tyrone III can be seen in **Figure 6** after many prototyping, redesigning, and challenges. The trade-offs is further discussed in the Vehicle Structure, Systems & Systems Approach

Figure 6: Final Tyrone III for Regional Competition

Innovation

Red Sea Robotics continuously seeks improvements as they believe the Tyrone III can achieve the maximum possible result. For instance, the engineers added two additional thrusters for ascending and descending. Based on the results of the last MATE ROV competition, Red Sea Robotics identified some shortcomings of the previous ROV, including a substantial lack of lift capability. Therefore, the Red Sea Robotics now has four lift motors, one on each corner. Not only does Tyrone III get a lift benefit, but now, much like a helicopter, airplane, or drone, Tyrone III can have a roll and pitch axis with the simple addition of the new thrusters. This allows for more precise maneuverability, and the roll enables the Tyrone III to not require a sway motor due to the swaying created by the thrusters, much like a drone would. The team also developed a more streamlined approach with the previous Tyrone II frame. As seen in **Figure 10**, last year's Tyrone II frame had a very boxy and inefficient design. Adapting this frame into a newer, more compact, and more streamlined design allowed for a smaller cross-section and, thus, greater efficiency of our design. This small cross-section can be seen in **Figure 8**. (Shrouds not present during construction in **Figure 8**).

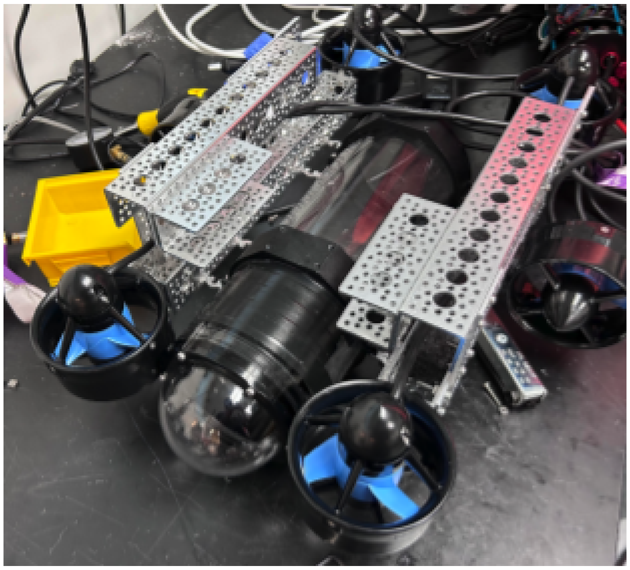


Figure 7: Improved Frame Structure for Gripper Arm

Further innovation with reduced cost can be noted regarding the motors. Due to the drone-like nature of the ROV, the ROV removes the need of additional thrusters significantly reducing build cost, as we can usually see ROVs, (especially bluerobotics ones) using upwards of 8 thrusters, with levels of maneuverability that our ROV achieves with only 6 In addition, our team was able to step away from off the shelf components such as the blue robotics framework, which could be and was replaced with a more cost-effective solution with our acrobatics frame. It's also important to note that the team used less material on this frame compared to last year, which is an excellent bonus for the team regarding responsible material usage and greater flexibility

Figure 8: Front View of Tyrone III

when adding new components; with new frame parts, we could later add.

Furthermore, the use of 'acrobatics' frame parts allows the team to mount motors, the capsule, and the grabber's arm reasonably quickly, with lots of opportunities to modify, should the need arise. Innovation is very active, and it is ever-changing with new requirements. Having a frame that can be adapted quickly is equally important to solving design problems as the solution, as without means to a solution, it may never be adequately implemented.

Our team decided to save costs in areas where it was deemed necessary. For example, the team used an ethernet cable rather than the Blue Robotics communications cable or reel for the tether. This ended up saving significant resources, significantly reducing construction costs. Furthermore, the team re-used the frame from last year's ROV because the construction was easy to modify. This lowered costs, reduced material waste, and gave the team a bounty of options for frame design, which was crucial for constructing an efficient and adaptable frame.

Problem-Solving

Red Sea Robotics started the new year with prototyping and reflecting on last year's competition. The team found that lack of components, overload of frame steel and tether were a dealbreaker. Therefore, the team took up the step and ordered necessary parts while also building new components. This allowed the team to improve our ROV and critically analyze what went right and wrong. By doing this, the team ensures that the ROV can achieve results more efficiently. For instance, the team began brainstorming different ideas for different skeletal frames for Tyrone III. This is illustrated in **Figure 9,** where the engineers collaborate and think critically about the efficient frame sketches that align with the rules and missions. Then, towards mid-January, the team started building frames and adding Blue Robotics parts.

Figure 9: Initial Brainstorming

Upon having exposure and experience from the 2023 World Championship, the Red Sea Robotics team evaluated and studied the Tyrone II (2023 version) and then improvised with brainstorming and implementing it into pool testing later on. The team concluded that having too much steel was a deal breaker as it added more weight and required more thrusters. The previous ROV only had four thrusters, so the team knew it needed more thrusters to move and complete the tasks efficiently. Hence, the team reduced the use of steel frames and emphasized making the thruster visible and open. Therefore, this has led to the disassembling of the steel frame and the implementation of a new design, as seen in **Figure 10**. This allowed for reduced mass and better stability and maneuvering in Tyrone III.

Figure 10: Disassembling Tyrone II (Previous ROV)

Additionally, the team used resources conservatively. This allowed for utilization of the parts needed for the ROV. The reused, bought, and built components are further discussed in [Build vs Buy & New vs Used]()

Vehicle Structure, Systems & Systems Approach

The Tyrone III ROV is our most advanced and reliable ROV to date. It features a compact and versatile structure built with lightweight Actobotics framing, six T-200 Blue Robotics thrusters for maximum power and lift, a Blue Robotics Newton Subsea Gripper Arm to achieve maximum tasks with reliability, and a Blue Robotics 6” series-sized watertight enclosure tube to hold all of our essential components. The Tyrone III is an incredible achievement for the entire Red Sea Robotics Team.

Figure 11: Gripper Arm

The horizontal length of the ROV is 0.58 meters, the total width is 0.46 meters, and the total height is 0.18 meters. This includes the top of the watertight enclosure and the bottom floor of the gripper arm. The weight of the Tyrone III is 8.14 kilograms. The weight and dimensions meet the mission requirements.

The Blue Robotics Newton subsea gripper arm was selected based on its capability and reliability while executing grabbing and manipulation functions. This gripper arm is firmly attached to the ROV's frame and can be operated using a controller from the control pilot station. The gripper's jaws open to 2.44″ or 0.062m, allowing the Tyrone III to assist in performing all necessary tasks. For instance, it can pull a pin to release the failed recovery float to the surface which is part of mission task 1. The gripper is rated at 300m, which is highly safe in shallow-depth environments. Although the gripper arm has an expensive price tag of $690 USD, the team decided to invest in it due to its reputation and ability to perform. It will be beneficial for meeting the mission requirements this year as the task mostly consists of grabbing, turning and transporting the props. Task 2, for example, requires a well-constructed grabber arm in order to move the wiring system through and around the props. Considering the magnitude of points that come with this task, it is pivotal that the ROV consists of a stable and powerful grabber arm. Grabbing the props requires strength and so the Newton subsea gripper arm has the ability to grab and transport it. So the team has invested in this as this is a big point scorer. This gripper was chosen because of the reliability and functionality that blue-robotics provides with their materials. If we were to use a grabber that was perhaps self-produced, we would run a far higher risk of product failure. When trying to isolate a motor underwater, there is the issue of actually waterproofing it, which involves isolating servos and/or motors, adding a level of complexity and unreliability that the team does not want to get involved with. Instead of that, a one-time purchase of a reliable bluerobotics grabber arm that could last a number of years seems to be a safer and more reliable option for the team. Another trade-off when choosing the gripper's arm was the limited axis of motion. Unfortunately, the gripper's left-to-right opening limits the ROV to tasks where objects are vertical. Horizontal tasks must be approached and possibly skipped due to the limited range of motion. A way to solve this problem would be to put the gripper onto a separate motor, allowing the grabber to spin if necessary.

The Actobotics framing system, constructed from lightweight aluminum materials, plays a crucial role in the overall structure of the ROV. This framing system offers a versatile and easy-to-assemble solution, providing a strong and sturdy framework for attaching the various components. The framing contains multiple holes that are compatible with all other types of Blue Robotics parts. This allows the engineers to easily connect thrusters, gripper arms, and capsules to our frame. The Actobotics framing system is ideal because it allows engineers to test multiple frame designs in a short period of time. When testing the ROV in a swimming pool, the team can easily change setups to fix issues or make adjustments. The trade-off of the Actobotics framing is that it can only be partially customized to the team's needs or the competition. Unfortunately, certain parts can not be connected quickly to the frame. The team hopes to explore more customizable frame options in the coming years.

When designing the Tyrone III, the team opted for six Blue Robotics T-200 thrusters for their reliable performance and precise maneuvering abilities. These thrusters play a crucial role in propelling and controlling the ROV while completing underwater tasks. To achieve efficient movement in different directions, the engineers positioned four thrusters in an upward configuration to maximize lift. This is one of the many new improvements from our previous ROV. In last year's competition, the previous ROV could not complete specific tasks due to limited lift capabilities; for example, when attempting to lift a relatively ‘light’ weight off the floor, the ROV could not lift it, but instead, the ROV destabilized resulting in a flipped ROV, almost causing serious piloting problems for the ROV. A similar issue came when we were trying to connect the carabiner to the hook on one of the tasks, and the ROV did not have the thrust to actually push the carabiner into the hook, resulting in an incomplete task due to a simple lack of thrust in the right area. Hence, to address these lessons and actually learn from them, the 4 up-thrusters and 2 thrusters close to the gripper allowed us to direct maximum thrust levels at times when we needed it. The Tyrone III has two side thrusters for maximum surge motion. These motors will also provide the ROV with yaw capabilities as well. This year, the team decided not to go with a sway motor as last year. This arrangement guarantees smooth and precise maneuverability, which is vital for effectively accomplishing underwater tasks. All cables from the thrusters run from each thruster into the Blue Robotics electronics capsule positioned in the center of the ROV. The trade-off of the blue robotics T-200 thrusters is the use of the high current. Unfortunately, this requires a higher tether gauge wire, resulting in more weight in the tether.

Electrical System

The electrical system is inspired by the Blue Robotics BlueROV2. The technical team made the decision not to use a motor controller, such as the Pixahawk seen in the BlueROV2, and to instead rely on a computer module, the Raspberry Pi 3 model B, on the ROV to receive controls and write to each of the 6 Blue Robotics T200 Thrusters, as well as to write to the Blue Robotics Newton Subsea Gripper. This decision was made so that sensors, such as the USB camera and the Blue Robotics “Celsius Fast-Response” thermometer, can be read and relayed to the surface in the same unit that handles controls and the thrusters. The signals are transmitted via an ethernet cable pair, linked by two FathomX Tether Interfaces on either end. The FathomX allows the signal to be used as an ethernet connection on both the Raspberry Pi and the surface computer, allowing for convenient SSH and remote GPIO control access.

The input from the Logitech Wired Controller is read and translated to thruster values on the surface with a Python program. The final thruster values are sent to the Raspberry Pi to directly write to the thrusters with minimal work on the Raspberry Pi’s end. The grabber arm and camera servo values are also calculated on the surface and sent to the ROV. The Raspberry Pi uses Gstreamer to run a 720p 24fps feed of the USB camera and streams it via ethernet to the surface, where Gstreamer then renders it. The code on the surface is designed with reliability in mind, meticulously tested so that errors will not occur, and in the case that they do, it is quick to restart the system in under 12 seconds.

12V power is supplied on a ten gauge wire with a 20A fuse. Power is first run through the surface control box, powering the surface FathomX board, then is sent along 15m of tether to the ROV. The tether consists of four wires in mesh sheath, two of which are ten gauge power, and the other two are 26 gauge ethernet. The ethernet wire is part of a 6-wire ethernet cable, which was used in case of changes to the design. However, ultimately, only two wires were used. According to Blue Robotics specifications, the FathomX supports HD video and signals on up to 300m ethernet tether. Therefore, 15m of tether is sufficient for our context. Power is distributed with two 8-circuit barrier blocks from DigiKey for 12V and ground. A Ubec 5V3A Boost Converter manages power to the Raspberry Pi, and each FathomX board is directly powered as it accepts 12V. The tether is secured with strain reliefs on both ends to prevent direct force on connections.

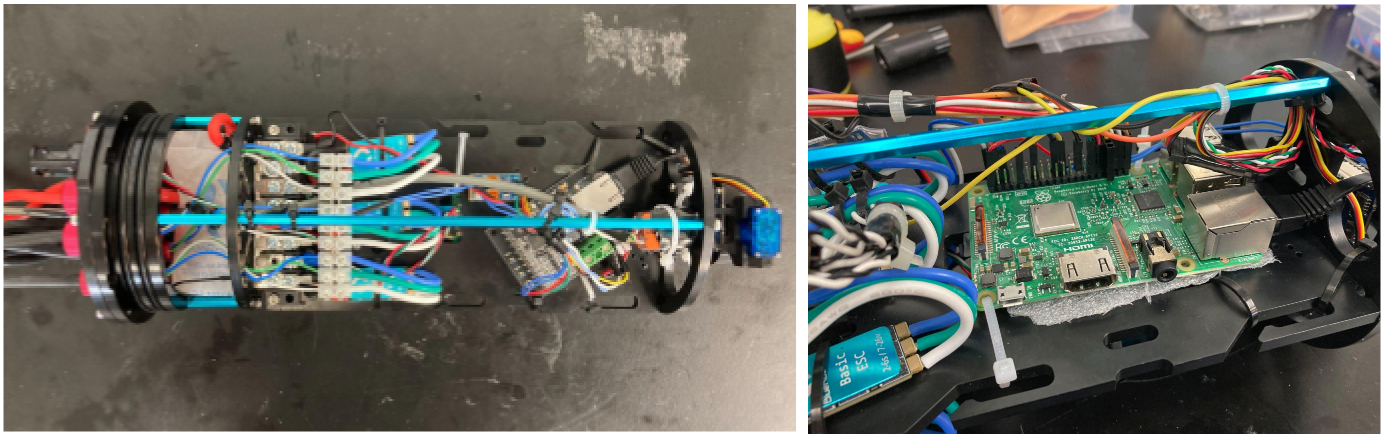


Figure 12: Electronic Capsule Components

Connections to the electronics capsule are ensured to be watertight using the Blue Robotics WetLink Penetrators, which are compatible with the endcap. The penetrators were sealed by engineers with an O-ring lubricated with silicon grease and potted using marine epoxy. Inside the ROV, the Blue Robotics Leak Sensor module is utilized by having two small humidity-sensitive sponges in critical points that close the circuit, indicating a leak and causing a persistent warning to appear on the surface computer. A silica gel packet will be placed in the connector's space, where a leak will likely occur.

The Tether is approximately 15 meters long and weighs 2.2 kg. This was decided based on the distance the tasks were around the swimming pool. The tether contains four wires: A 10 gauge power, a ten gauge ground, and an ethernet wire pair for communications. The electrical decisions behind the tether are described in the Electrical Section. The tether would be an efficient length for Tyrone III, ensuring that Tyrone III did not have too much or too little, as too much length could cause signal noise, and too little would limit Tyrone III's ability to complete tasks.

The team added a series of tether flotations consisting of pool noodles cut into small sections and placed in intervals across the tether to float the tether and not create drag. The team also did not include a roll or spool wheel for the tether, as the tether has to completely mitigate the risk of kinks, as well as the risk of tether output. At some points, the tether operator needs to give out large lengths of tether into the water to meet the ROV's needs.

To manage the tether, the tether operator communicates with the pilot and the rest of the team. They use specific commands and signals to coordinate the deployment and recovery of the tether, ensuring the ROV has the necessary length while preventing snags or tangles. If the tether becomes snagged or difficult to see, the tether operator can use the ROV's camera to inspect the tether and assess if it is moving freely or has become stuck. This allows the team to quickly identify and address any tether management issues that could impact the ROV's performance and safety during the competition tasks.

Altogether, a tether operator is utilized that constantly feeds or removes the tether from the water to keep the ROV controlled and the tether management system effective and efficient.

Propulsion

The team chose Blue Robotics T200 Thrusters for the Tyrone III because they worked well in the previous ROV. Using the same type of thruster will make it easier to fit them into the new ROV design since the team is already familiar with them. The team added six thrusters to improve the Tyrone III's stability and ability to move around. They put four thrusters pointing up and two pointing forward. This setup gives the ROV balanced power and good control over its movement in all directions. The T200 Thrusters cost $200 each. These thrusters are known to be reliable and powerful, which is important for the difficult tasks the Tyrone III will have to do. The team has used these thrusters before and has been happy with how they perform. The T200 Thrusters' high power compared to their weight makes them good for tasks that need fast acceleration, precise positioning, and the ability to work against strong currents. This power and control is crucial for things like navigating through tight spaces, holding still during delicate work, and quickly responding to changes in the water. The thrusters are also built to be tough and waterproof, so they can handle the pressure and hazards of the underwater environment. This reliability reduces the chances of problems during important moments, allowing Tyrone III to work confidently throughout the competition.

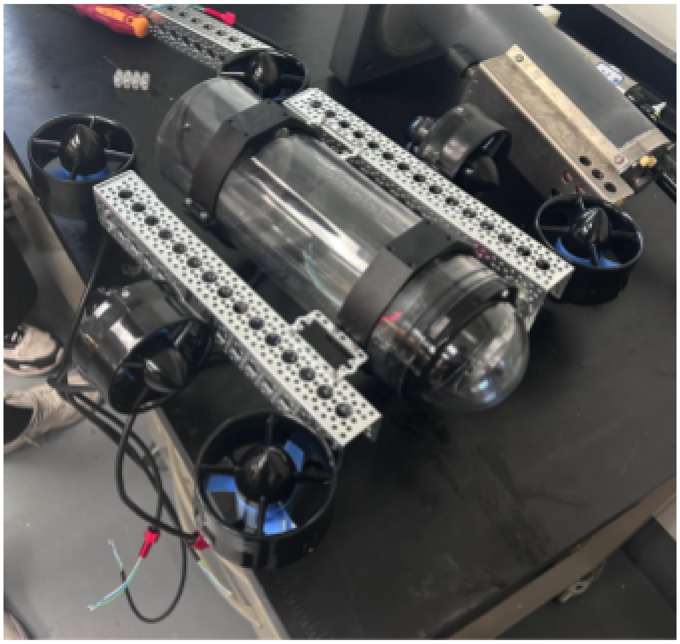


Figure 13: Thrusters

The ROV gains superior stability and buoyancy control by having four thrusters oriented upwards. In other words, the upward thrusters can lift heavy objects underwater. These upward-facing thrusters counteract the weight of the Tyrone III, which allows the ROV to maintain a stable position underwater. Additionally, this configuration enables the ROV to execute vertical movements, such as ascending and descending, with ease and stability. Meanwhile, the two thrusters facing forward serve to enhance the ROV's forward propulsion and maneuverability. Placing thrusters in this orientation allows the ROV to move efficiently through the water, overcoming resistance and achieving higher speeds. Moreover, having forward-facing thrusters enables the ROV to execute complex maneuvers. The placement of six thrusters is seen in **Figure 13.** (Shrouds not present during construction in **Figure 13**)

Buoyancy and Ballast

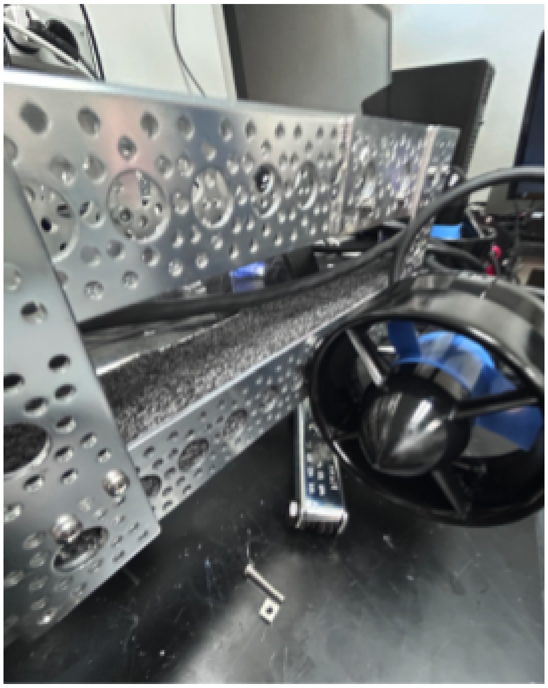


Figure 14: Foam Inside the Frame

The frame utilizes a system of integrated flotation to maintain buoyancy in the ROV. With the Tyrone III, the team aims to establish complete neutral buoyancy. Since the Tyrone III has a heavy aluminum frame, six motors, and a grabber, there is a substantial level of negative buoyancy. To counteract this, Tyrone III underwent an operation where the team installed foam in the empty sections of our U-shaped framework, as seen in **Figure 14**. It is also important to note the effect of the positioning of the grabber arm and the placement of the electronics capsule. The electronics capsule doubles as a source of ample buoyancy, as it has a large air volume, increasing its' positive buoyancy coefficient. There is, however, an issue of ballast on the ROV due to the placement of our grabber arm. The grabber arm, which has a noticeable mass, is placed on the front of the ROV (see **Figure 11**). Thus, this placement causes a forward-pitching motion of the ROV, which should be avoided. To counteract this, the team added more flotation in our integrated systems closer to the front of the ROV. The Tyrone III is expected to be capable of lifting heavy objects. Therefore, the team has decided to keep two lift motors close to the front of the ROV to counteract this front tilting motion that the ROV would experience should it lift or manipulate an object. (Side note: the team tries to establish the most symmetrical ROV they can to maintain a flat and level ROV attitude when not maneuvering.) Furthermore, the ROV can encounter situations where heavy objects need to be swayed from side to side. To address this ballast issue with movement, the ROV can use roll to its advantage. Like a drone, the roll motion combined with heave inputs on the upwards-facing thrusters can create a rather powerful sway motion as the ROV is rolled onto its side, repurposing all 4 heave thrusters into sway thrusters.

Payload and Tools

The Tyrone III has one 720p USB camera as it effectively gives the pilots a clear view underwater while being energy efficient. The camera is placed within the watertight enclosure and attached to a servo, allowing for vertical rotation, primarily to keep the gripper in view when convenient, as seen in **Figure 15**. The camera feed is streamed with Gstreamer on the ethernet tether to be rendered on the surface computer, as seen in **Figure 16**.

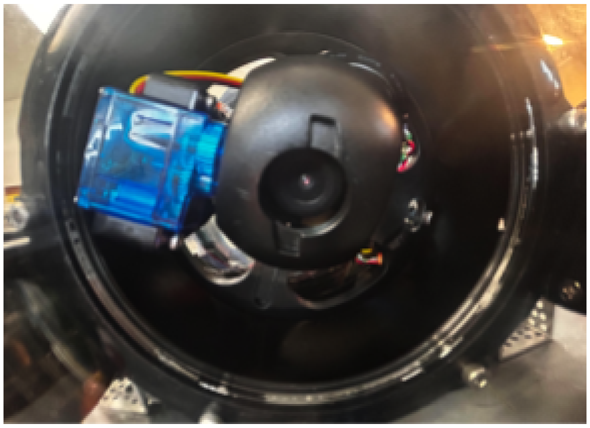


Figure 15: Tyrone III Camera

Other essential tools utilized in Tyrone III consist of the Newton Subsea Gripper, six T200 Thrusters, and the Watertight Enclosure. The Gripper handles items and recovers them in several underwater mission tasks. For instance, one of the mission requirements is to grab a rock and deliver it outside. To meet this requirement, the pilot can see the gripper arm below and effectively grab and transfer the rock to the outside. The BlueRobotics Thrusters provide efficient propulsion and accurate movement, allowing for navigation underwater and completing the task and mission; the trade-off is discussed in Vehicle Structure, Systems & Systems Approach. The watertight enclosure protects critical electrical components, increasing protection and longevity in underwater circumstances. Together, these payload tools enable the Tyrone III to effectively conduct a wide range of activities, helping to the effectiveness of underwater operations in various situations and tasks required to complete. Additionally, the sensors in Tyrone III are discussed in Electrical Systems.

Figure 16: Monitor Footage from Tyrone III Camera

Build vs. Buy & New vs. Used

Red Sea Robotics strongly believes in reusing materials to be sustainable and efficient in building the Tyrone III. The team has used chiefly parts from the previous ROV, Tyrone II, that was successful in the international competition of 2023. However, Red Sea Robotics also bought new parts that were necessary to improve the ROV. It is to be noted that Red Sea Robotics was short on budget (further discussed in Accounting), so the team had to be wise with spending and reusing specific components. Therefore, the team reused steel frames to minimize the cost of buying them and meet the weight limit. We decided to continue using these steel frames as they met our requirements well and allowed us to compete to a satisfactory level last year.

Additionally, the team reused the watertight enclosure, four thrusters, and an electronics capsule. However, the team has bought the Newton Subsea gripper Arm, Raspberry Pi Processor, Tether, and two new Blue Robotics Thrusters for improved movement options. This upgrade will meet the mission requirements as having more thrusters means that the Tyrone III can efficiently do vertical profiling and vector thrust. This will ensure that the task is met, for example the thrusters will be able to help lift heavy objects such as grabbing the carabiner and dragging it to a new location. Nonetheless, below is the list table of reused, built, and purchased.

Built, purchased, or reused, Red Sea Robotics believes in ensuring parts are fitted considering all aspects of development from costs, performance, and sustainability in terms of environmental impact.

Reused	Built	Purchased
- Steel Frame - Watertight Enclosure	- Safety Guard - Tether - Surface Control Box	- Newton Subsea Gripper - Rotation Servo - Arduino Nano - 25m Sheath - 25m cable - Camera - FathomX Interface - 6 T200 Thrusters

Safety

Our Philosophy

Red Sea Robotics takes pride in putting everyone's safety first. We guarantee that all our team members are safe and comfortable, allowing them to do the most outstanding quality job possible. We want to provide a secure atmosphere in which our members may master their skills and demonstrate their abilities on a worldwide scale. Our members strictly adhere to the Job Safety Analysis to guarantee safe launch, recovery, and waterside operations below and above water.

Safety Content & Procedures

Red Sea Robotics' priority is the safety and well-being of its members. To guarantee this, all members must wear particular personal protection equipment, such as safety glasses, shoes/boots, lab coats, and gloves, at all times. A fire extinguisher, eyewash station, and first aid kit should all be readily available in the lab. All danger and warning zones are correctly marked with neon and visually recognizable signs. All team members are required to strictly follow lab rules and procedures with no margin for mistakes.

The ROV's body form and structure are designed to be as robust and rigid as possible, with safety and efficiency as the top priorities. Wires, fasteners, connections, and sealants are carefully selected to avoid underwater issues. The thrusters have thruster guards to prevent blade injuries and things from being lodged. These guards fulfill IP-20 specifications, guaranteeing the mesh size is below 12.5mm. All electronic components are safeguarded

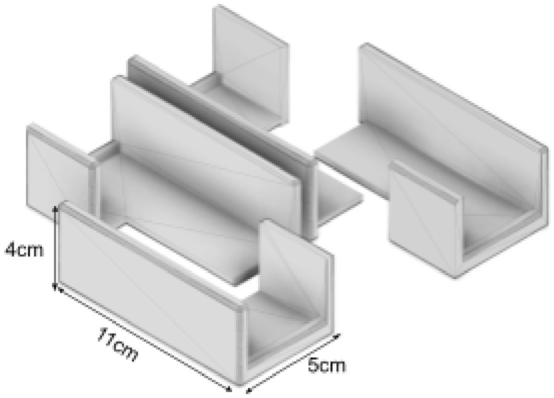


Figure 17: Safety Guard for Edge Steel Frames

by enclosing them in a clear acrylic tube sealed with end caps with double O-rings on each side, and the end caps are clamped down with 6 M3 bolts on either end. While above water, the ROV is intended to be carried by its frame to eliminate the need for handles and facilitate more straightforward transportation. All fastenings and safety attachments were also smoothened to ensure that the fixtures were not a safety hazard. There has been a leak sensor installed in the ROV, which could detect leaks and warn the ROV pilot to bring the ROV back to the surface and power it off in the case of a leak. Additionally, we have installed 3D-printed safety guards onto the aluminum steel frame to enhance the safety of the ROV. An example of our safety guard is seen in **Figure 17.** The safety checklist and job analysis are in Appendix B and Appendix C, respectively.

Critical Analysis

Testing and Troubleshooting

The methodology of testing the ROV involved assessing three key aspects: motor speed, motor lift, and lift capacity. The six Blue Robotics T-200 thrusters were individually tested to evaluate motor speed. The ROV was placed in a controlled environment, and the speed of each thruster was measured using appropriate instrumentation. This allowed the engineers to ensure that all thrusters were functioning optimally, providing consistent and reliable propulsion for the ROV.

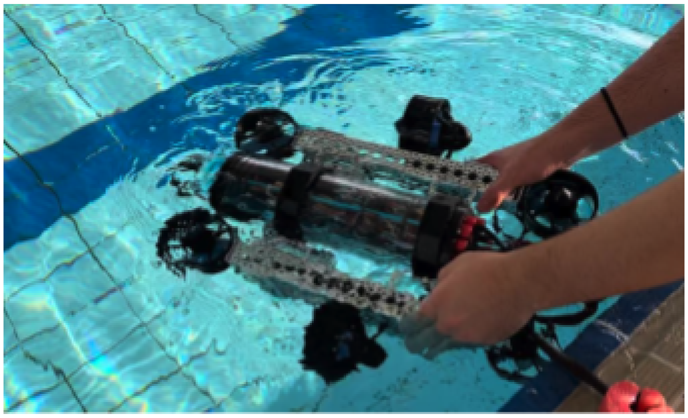


Figure 18: Testing Tyrone III in the pool

The motor lift capability was tested by gradually increasing the load applied to the ROV's gripper arm. Starting with minimal weight, different objects of increasing mass were securely picked up using the gripper arm. The ROV's ability to lift and maneuver the objects was observed and recorded. This test ensured that the motor lift mechanism could effectively handle the expected loads during operational tasks.

The lift capacity of the ROV was determined by progressively increasing the weight of objects being lifted until the ROV reached its maximum lifting capacity. This test allowed the team to establish the maximum weight the ROV could safely handle without compromising its stability or performance. It provided valuable information for operational planning and ensured that the ROV's capabilities were aligned with the intended tasks.

Data such as motor speed, lift capacity, and any observed anomalies or issues were documented and analyzed throughout the testing process. This allowed the team to identify any performance limitations or areas for improvement and make necessary adjustments to optimize the ROV's functionality and reliability.

By conducting comprehensive testing of motor speed, motor lift, and lift capacity, we ensured that the Tyrone III ROV's propulsion and lifting systems were functioning as expected and capable of meeting the operational requirements of our underwater tasks.

Testing Data:

Motor Thrust Setting (%)	Forward/Backward Motor Speed (ms^{-1})					Average
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	
40	0.505	0.487	0.476	0.457	0.500	0.485
50	0.575	0.561	0.575	0.544	0.577	0.566
60	0.671	0.657	0.628	0.674	0.667	0.659

Motor Thrust Setting (%)	Up/Down Motor Speed (ms^{-1})					Average
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	
40	0.757	0.745	0.758	0.765	0.777	0.760
50	0.804	0.813	0.833	0.823	0.842	0.823
60	0.878	0.902	0.921	0.895	0.945	0.908

Motor Thrust	
Direction	Thrust (kg ± 0.0005)
Forward	4.8200
Backward	3.7800
Up	9.6500
Down	7.5900
Left	N/A (lack of sway motor)
Right	N/A (lack of sway motor)

Accounting

Budget

Red Sea Robotics faced a significant loss when the previous year's sponsor withdrew at the beginning of the season. Hence, the team had to be both creative and cost effective with the budget. With some initial funding from KAUST of around 3000 USD, Red Sea Robotics prioritized buying necessary components such as gripper arms, thrusters, and a tether. These were prioritized because of their individual importance and immense contribution to the performance of the rover, as mentioned in previous sections of the documentation. The team planned out the essential parts required in shared documents where the parts would be ordered and shipped. Each team member wrote the parts needed for the shared document. Then, the prioritized parts were ordered. The actual money spent on components is roughly 2500 USD, with the rest of the components either being donated or reused. However, it should be noted that, in some cases, the shipping cost is not included, so the value may exceed the expected total cost. Furthermore, there are different types of funds. As seen in the 'Fund Type' column on the cost accounting table, The 'Sponsored' Fund type is the money being funded to Red Sea Robotics, and 'reused' is the material that has been used before and is being used again. The 'Donated' fund type is when another organization provides Red Sea Robotics with the product, whereas 'Purchased' is when the Red Sea Robotics team spends its own costs (coming from members of the team).

Cost Accounting

Category	Expenses + Description	Quantity	Fund Type	Total Cost (USD$)
Hardware	Bluerobotics Newton Subsea Gripper	1	Sponsored	690.00
Hardware	Actobotics Frame Sections	1	Reused	231.00
Hardware	Rotation Servo	3	Sponsored	25.00
Hardware	RC controller	1	Sponsored	42.00
Electronics	Arduino Nano	1	Sponsored	65.00
Other	Thermometer	1	Sponsored	70.00
General	~25m Sheath	1	Sponsored	64.00
General	~25m Cable (10 Gauge)	1	Sponsored	85.00
Electronics	Camera	1	Sponsored	99.00

Electronics	FathomX Interface	1	Sponsored	120.00
Other	Syringe 150ml	2	Sponsored	15.00
Hardware	Bluerobotics T200 Thrusters + ESCs	6	Sponsored	1,428.00
Hardware	Bluerobotics 4” Acrylic Tube + Covers and Plugs	1	Sponsored	213.00
Electronics	Raspberry Pi 4	1	Sponsored	100.00
Electronics	Breadboard	2	Donated	15.00
Hardware	Watertight Enclosure (0.1 m)	1	Sponsored	230.00
Hardware	End Cap (0.1 m) 18 x M10 Hole	1	Sponsored	55.00
Hardware	O-Ring Sealing Flange (0.1 m)	2	Sponsored	90.00
Hardware	Eng Cap (0.1) Dome	1	Sponsored	40.00
Hardware	Vent/Pressure Relief Valve	1	Sponsored	10.00
Hardware	Potted Cable Penetrator	9	Sponsored	45.00
Hardware	Penetrator Blank	6	Sponsored	30.00
General	25A Fuse Package	1	Purchased	6.67
Electronics	Fuse Holders	6	Purchased	16.38
Electronics	Arduino Wireless Bluetooth Controller	1	Purchased	9.61
Hardware	Strain Relief	1	Sponsored	24.98
Hardware	Hard Shell Control Box	1	Sponsored	50.00
Travel	Transportation between KAUST and Jeddah Airport (includes return prices)	1	Sponsored	~300
Travel	Flight Tickets From Jeddah to Kingsport (includes return prices) (note: chaperone is not included in cost)	8	Sponsored	~19,200.00
Travel	Hotel Accommodation	8	Sponsored	~5,000
Travel	Car Rental (Minivan) in Kingsport	1	Sponsored	~1,500

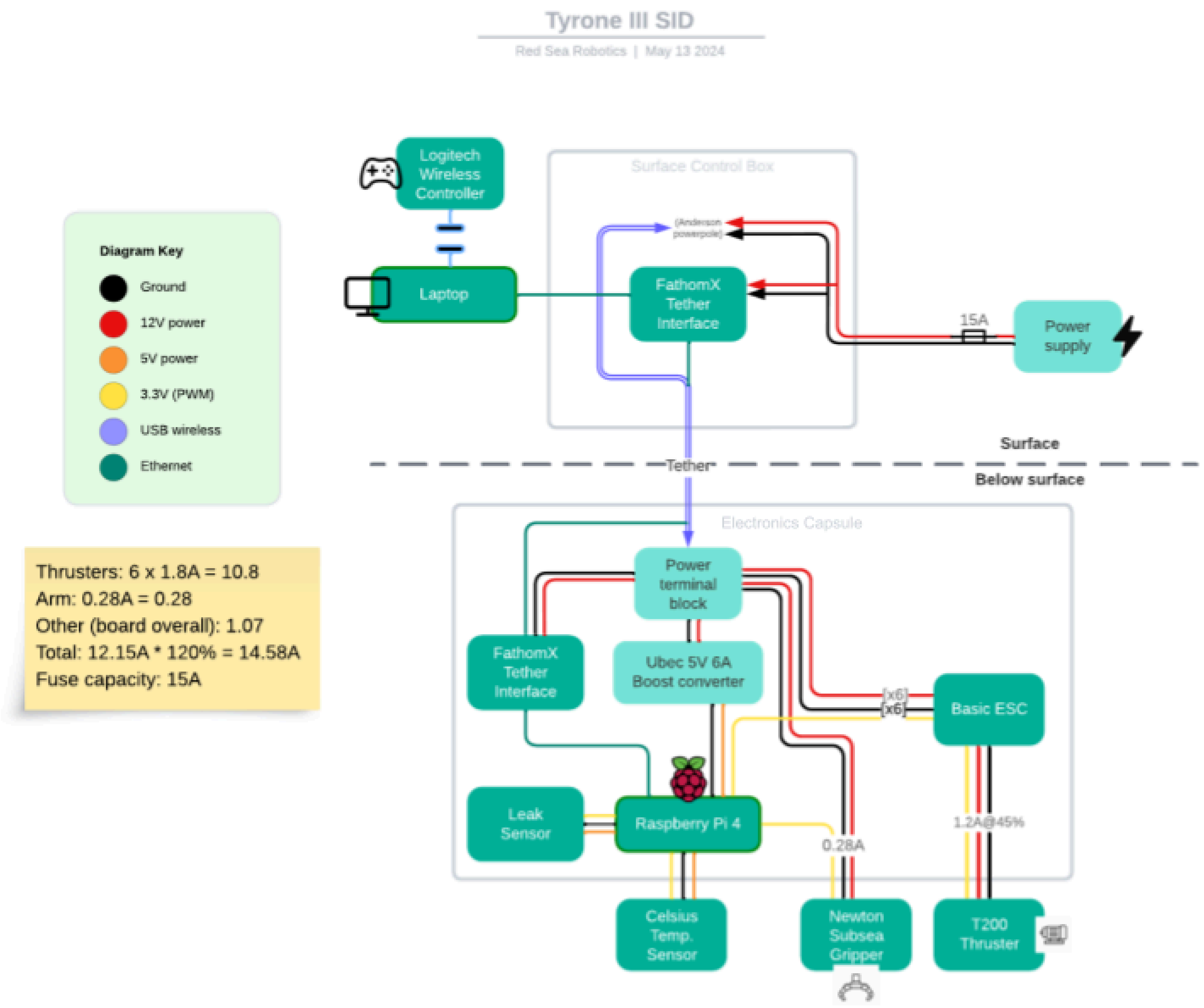
Travel	Food	8	Sponsored	~2,500
Merchandise	T-Shirts and Hats for Regional Competition	9	Purchased	130
Merchandise	Team Polo Shirts, Hoodies, Hats, Banners, etc.	24	Purchased	250
			Total	32,449.64

Acknowledgments

The Red Sea Robotics would like to express enormous gratitude and appreciation for the opportunity to participate in the 2024 MATE ROV program for the second time. We are immensely thankful to the MATE Center, Marine Technology Society, and our various internal sponsors for their significant contribution to our journey. We thank the KAUST Coral Restoration Initiative for immense and crucial funding enabling us to travel to the United States of America for the world competition. The KAUST Enrichment for Youth (KEY) has been instrumental in organizing the regional competition and logistics. We would like to extend our hands to KAUST Coastal and Marine Resources Core Lab for their funding, assistance, and resources, and, lastly, The KAUST School for their help and the opportunity to participate in the MATE ROV program and financial support in sponsoring the team with critical ROV parts. Additionally, we would like to thank our supervisor for their generous assistance with equipment and guidance. Furthermore, we take great pride in representing Saudi Arabia for the second time in this prestigious competition, showcasing our commitment to marine technology and education that drives a sustainable future. We are deeply grateful for the invaluable support we have received. Lastly, the team would like to thank and acknowledge the support from our parents, who have been pivotal in encouraging us to push through challenges, and to allow us to be part of this meaningful journey.

Appendix

Appendix A: Tyrone III ROV's SID



Thrusters: 6 x 1.8A = 10.8
Arm: 0.28A = 0.28
Other (board overall): 1.07
Total: 12.15A * 120% = 14.58A
Fuse capacity: 15A

Appendix B: Job Safety Checklist

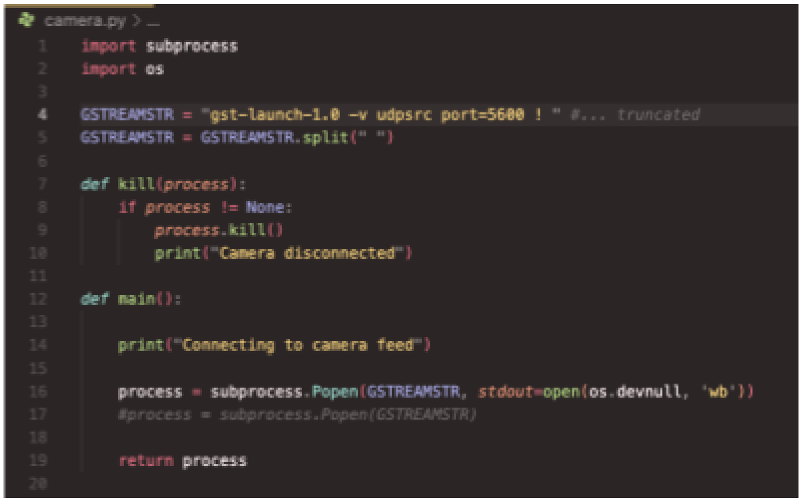
Precaution	YES	NO
Personal Protective Equipment (PPE) - Ensure all team members are wearing PPE such as safety glasses, gloves, and closed-toe shoes to protect against physical and chemical hazards. - Ensure team members are wearing appropriate clothing that does not pose a risk of entanglement or snagging in machinery.		
Emergency Procedures - Have a clearly defined emergency plan in case of an accident, including emergency contacts, evacuation routes, and first-aid procedures. - Conduct regular safety drills to ensure all team members know what to do in case of an emergency.		
Equipment Safety - Inspect and test equipment before use to ensure it is in good condition and functioning properly. - Ensure all equipment is properly maintained, cleaned, and stored after use. - Use equipment only for its intended purpose and follow manufacturer instructions.		
Electrical Safety - Ensure all electrical equipment is properly grounded and meets safety standards. - Use circuit breakers, fuses, and other protective devices to prevent electrical hazards.		
Hazardous Materials - Identify and properly handle any hazardous materials used in the robotics laboratory, such as chemicals, batteries, and lubricants. - Ensure all hazardous materials are properly labeled, stored, and disposed of.		
Fire Safety - Have appropriate fire extinguishers readily available and ensure team members are trained on their proper use. - Regularly inspect and maintain fire suppression systems and smoke detectors.		

Appendix C: Job Safety Analysis

Job	**Hazards**	**Controls**
1. Mechanical Engineer	Heavy Lifting, Chemical Burns, Blade Cuts, Moving Parts and Pinch Points	Heavy Lifting course, Blade Safety Rules, Pinch Points Safety Lesson, Lab Safety Course and Rules
2. Electrical Engineer	Electrocution, Soldering Burns, Heat Gun Burns, Shorting Equipment, Exposed Wires	Soldering and Electrocution Safety Course, Heat Glove enforced during use of Heat Gun and Soldering Iron, Lab Safety Course and Rules
3. Pilot	Electrocution, Drowning, Robot Catching on Fire, Blade Cuts, Controls Exploding	Pool Safety and Swimming Aptitude Test, Life Guards on Duty at all times, Fire Safety Course, First Aid Basic Course, Blade Safety Rules, Lab Safety Course and Rules
4. Tetherman	Electrocution, Drowning, Robot Catching on Fire, Blade Cuts, Controls Exploding	Pool Safety and Swimming Aptitude Test, Life Guards on Duty at all times, Fire Safety Course, First Aid Basic Course, Blade Safety Rules, Lab Safety Course and Rules
5. Co-Pilot	Electrocution, Drowning, Robot Catching on Fire, Blade Cuts, Controls Exploding	Pool Safety and Swimming Aptitude Test, Life Guards on Duty at all times, Fire Safety Course, First Aid Basic Course, Blade Safety Rules, Lab Safety Course and Rules
6. Frame Builder	Cutting Tools, PVC Shattering, Hot Glue Burn, Chemical Burn and Paint Poisoning	Blade Safety rules, Gloves being worn during construction processes, Chemical Safety rules and Lab Safety Course and Rules
7. Chief Financial Officer	Carpal Tunnel, Workplace Stress, Office Hazards	Arm Exercises to reduce strain of wrist, Daily Meditation and Mindfulness Sessions, Lab Safety Course, Office Safety Course
8. Chief Executive Officer	Carpal Tunnel, Workplace Stress, Office Hazards	Arm Exercises to reduce strain of wrist, Daily Meditation and Mindfulness Sessions, Lab Safety Course, Office Safety Course
9. Non-ROV Tetherman	Electrocution, Drowning, Robot Catching on Fire, Blade Cuts, Controls Exploding	Pool Safety and Swimming Aptitude Test, Life Guards on Duty at all times, Fire Safety Course, First Aid Basic Course, Blade Safety Rules, Lab Safety Course and Rules
10. Non-ROV Dataman	Electrocution, Drowning, Robot Catching on Fire, Blade Cuts, Controls Exploding	Pool Safety and Swimming Aptitude Test, Life Guards on Duty at all times, Fire Safety Course, First Aid Basic Course, Blade Safety Rules, Lab Safety Course and Rules
Required Training: **-Lab Safety Course** **-Pool Safety and Swimming Aptitude Test** **-First Aid Basic Course** **-Pinch Points Lesson and Blade Safety Rules** **-Safe Heavy Lifting Course** **-Mindfulness and Stress reduction Course**	**Required Personal Protective Equipment (PPE)** **- Lab Coat** **- (PPE Certified) Lab Goggles** **- (PPE Certified) Heat Resistant Gloves** **- (PPE Certified) Boots with Metal Frame**	

Appendix D: Tyrone III Software Code

```python
        # Joystick axes smoothing
        axes = {
            "axisLeftX": joystick.get_axis(0),
            "axisLeftY": -joystick.get_axis(1),
            "axisRightX": -joystick.get_axis(3) * 0.5,
            "axisRightY": -joystick.get_axis(4)
        }

        for axis in axes:
            axes[axis] = mapJoystickAxis(axes[axis], -1, 1, DEADZONE)
            textprint.tprint(screen, "Axis {}: {}".format(axis, getFloatStr(axes[axis])))

        # Axes to thruster map
        moves = {
            "FrontLeft": (-axes["axisLeftY"]) + axes["axisRightX"],
            "FrontRight": axes["axisLeftY"] + axes["axisRightX"],
            "UpBackLeft": axes["axisRightY"],
            "UpBackRight": axes["axisRightY"],
            "UpFrontLeft": axes["axisRightY"],
            "UpFrontRight": axes["axisRightY"]
        }

        damper = 0
        for move in moves:
            moves[move] = clamp(moves[move], -1, 1)
            damper += abs(moves[move]) * 0.03

        textprint.unindent()
        textprint.unindent()
        textprint.tprint(screen, "")
        textprint.tprint(screen, "Thruster values:", "gray")
        textprint.indent()
        textprint.tprint(screen, "Damping ratio {}%%".format(getFloatStr(damper)))

        # Apply thruster values to thrusters
        for move in moves:
            final = moves[move] * POWER * (1 - damper) * moveratios[move]
            textprint.tprint(screen, "{}: {}".format(move, getFloatStr(final)))
            thrusters[move].value = final
```



```python
import subprocess
import os

GSTREAMSTR = "gst-launch-1.0 -v udpsrc port=5600 ! " #... truncated
GSTREAMSTR = GSTREAMSTR.split(" ")

def kill(process):
    if process != None:
        process.kill()
        print("Camera disconnected")

def main():

    print("Connecting to camera feed")

    process = subprocess.Popen(GSTREAMSTR, stdout=open(os.devnull, 'wb'))
    #process = subprocess.Popen(GSTREAMSTR)

    return process

```

References

“2024 MATE ROV COMPETITION TECHNICAL DOCUMENTATION SCORING REQUIREMENTS - EXPLORER, PIONEER, RANGER.” MATE-ROV Competition, https://20693798.fs1.hubspotusercontent-na1.net/hubfs/20693798/2024_TechnicalDocumentation_EXPNRN_Scoring_Criteria_v0-1.pdf.