TKS REEF ROVERS

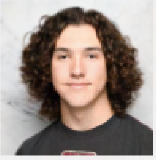
Technical Documentation

The KAUST School

King Abdullah University of Science and Technology

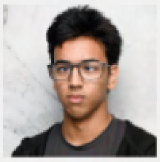
Saudi Arabia

The Team



CEO, Pilot

Emils Ekers



CFO, CCO, Co-Pilot

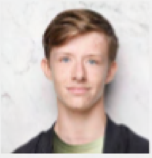
Yahya Fahmy

CTO, Software Engineer

Dylan Todorov

Head of Mechanical Engineering, Tetherman

Reuben Potter



Head of Electrical Engineering

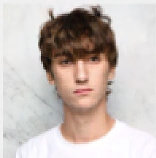
Jacob Kennedy

Task Tool Specialist

Lilian Tryon

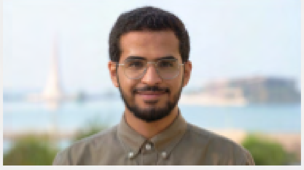
Frame Builder

Nitin Prabhu



Safety Officer

Oliver Horvath

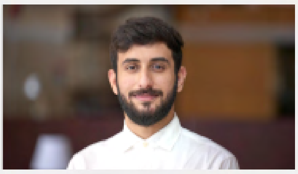


Nawaf Alotaibi

Mentor

Education
2020.08 - 2022.05 M.S. Student in Mechanical Engineering, KAUST, KSA 2016.08 - 2020.05 B.S. in Mechanical Engineering, Georgia Institute of Technology, USA

Professional Profile
2019.06 - 2019.08 Research Intern, RISC Lab, KAUST, KSA



Majed Alshamrani

Mentor

Education
2021.08 - Present M.S. Student, King Abdullah University of Science and Technology, KSA
2017.08 - 2021.05 B.S., Texas A&M University, USA

Professional Profile
2020.06 - 2020.08 Research intern, VIRTUAL, Communication Lab, KAUST
2018.06 - 2018.08 Research intern, Semiconductor Power Electronics Center, University of Texas, Austin, USA

Table of contents

Abstract

The TKS Reef Rovers is a student-based company aiming to drive innovation and growth in underwater ROVs. Our company carefully selected the members' roles based on their strengths and passions, allowing our work to be as efficient as possible. We spent countless hours over the past 8 months designing a versatile and valuable robot to complete underwater tasks. This is our first entry into the competition, and we are confident in our dedication to performing well. Our ROV features 4 efficient motors placed in a manner which allows easy and intuitive control by the pilot. Our robot also has a powerful grabber arm, allowing it to complete many complex tasks during the regional competition. Not only does this ROV solve colossal world problems, but also brings the opportunity for students from The KAUST School to express their unique skills and talents in a larger-scale scenario.

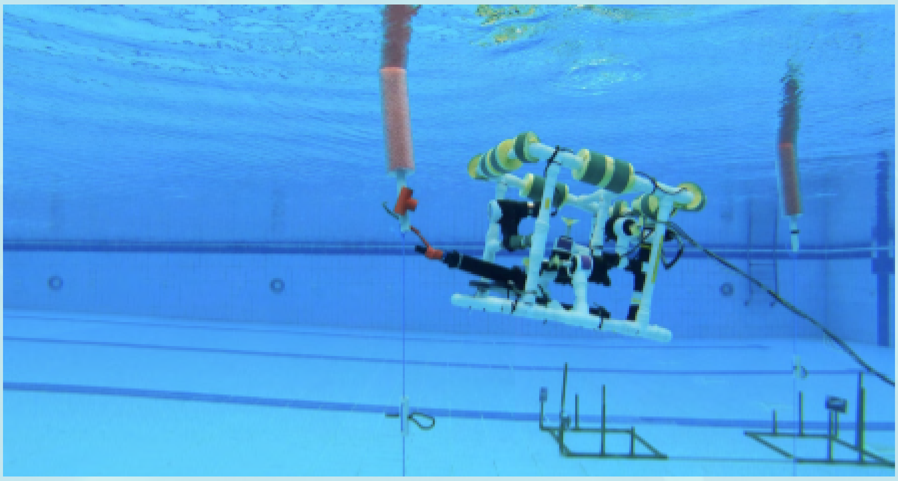


Figure 1: Tyrone completing tasks in regional competition

Project Management

When TKS Reef Rovers first accepted the call to compete in its home hosted 2023 competition, members of the company were all given the opportunity to learn the necessary skills from mentors to engineer the ROV.

After working, there were several advancements made in three main fields; Mechanical, Electrical and Software. To stay organized and to work efficiently, the team decided to use Gantt charts as an action plan, shared with each of the team members so that they can know what to do and when to do it. An example of a Gantt chart used by the team is shown down below. The Gantt chart acted as a functioning action plan as well as a suitable company schedule

Task	Deadline	Emils	Dylan	Yahya	Oliver	Nitin	Reuben	Jacob	Lily
Complete technical documentation	22 May 2023								
Revise and finish	24 May 2023								
look into tasks and get specifics	28 May 2023								
Rebuild frame including shrouds and wire strain reliefs	30 May 2023								
Attach sensors: gyro, rangefinder	6 Jun 2023								
Look into getting digital camera	10 Jun 2023								
possibly get main board in the rov, and controls above water via tether	10 Jun 2023								
reprogram and wiring	14 Jun 2023								

Figure 2: Task checklist used by team

Teamwork

Company Overview

Our company aims to design, plan, and build advanced underwater remotely operated vehicles (ROVs) that showcase the creativity of unique marine robotics technology. As part of the MATE ROV competition for 2023, we are excited to collaborate with industry partners and university student mentors to improve our ROVs' design and functionality.

We are focused on creating ROVs equipped with advanced technologies such as high-definition cameras, thrusters, and manipulators' arms, enabling us to perform complex tasks underwater.

Our company comprises skilled and committed employees with varying interests, research scientists/students, and technicians dedicated to advancing marine robotics technology. We believe in the power of technology to change the world, and we view our work as a way to make significant contributions to the marine industry.

Throughout this year's program, our company has worked tirelessly with each member contributing their qualities. These efforts have helped us successfully bring our idea to life. TKS Reef Rovers’ first product, Tyrone, aims to inspire the next generation of marine scientists and engineers while demonstrating the capabilities of our advanced technology. Ultimately, we aim to win the MATE ROV competition and gain recognition for our cutting-edge design, endless efforts, and engineering capabilities.

Resource, Procedures, and Protocols

Resource management, processes, and protocols were essential components in bringing success to our company. Firstly, assets such as funds and materials were managed based on the team's needs. Resources were used according to the requirements and only used when necessary. This approach was essential in preventing avoidable costs and a waste of resources overall, which could be used to develop and maintain the ROV.

Furthermore, we managed procedures and protocols to meet mission objectives and solve day-to-day operational problems systematically. The following are the steps we take:

1. Identifying objectives: We start by identifying our objectives. This involves setting Specific, Measurable, Achievable, Relevant, and Time-Bound (SMART) goals that meet our needs
2. Establishing a plan: We establish a plan that outlines the steps we will take to achieve our objectives. The plan should consider both the day-to-day operational problems and the mission objectives.
3. Assigning responsibilities: We assign specific responsibilities to each team member based on their strengths and expertise. This ensures that everyone understands what they are responsible for and works towards achieving the objective.
4. Monitoring and evaluating progress: We put in place measures for monitoring and assessing progress towards achieving our objectives. This helps us identify potential problems and make adjustments promptly.
5. Reviewing and updating procedures and protocols: We continually review and update our procedures and protocols to ensure they remain relevant and effective.

We continually work to improve our processes to ensure we achieve our objectives efficiently and safely.

Design Rationale

Buying vs Building

We decided to try building most aspects of the ROV from separate parts as it's cheaper and more manageable to get the custom result we want. For example, the frame is built from cut PVC pipes, and the control box is a combination of various electrical components being used. We decided to build these parts as it allowed for maximum customisation and let us attain the exact result we want.. However, some specific parts were bought pre-built, for example the BlueROV grabber arm and the Triggerfish control box to make building this project faster and easier for the team. Some parts, like the grabber arm, were bought because it would be more reliable and effective than anything our team could've put together at the time.

New vs Re-used

Most areas of the ROV are re-used or repurposed existing parts, for example we intergrated a parking camera, and a previously used Raspberry Pi was recycled for this project. This allowed us to save costs and not amass unnecessary expenditure. Some parts needed to be bought new, as they are either hard to come by, or need to be of optimal condition before use.

Frame Design Rationale

The mechanical team created a high-quality frame that met our company's expectations. To achieve this, the team studied the documentation of past MATE World Championship-qualified teams. This was useful in understanding the various approaches teams took toward the competition. The company underwent a technical training phase to review the physics and design theories related to our product, mainly through the design courses provided at The KAUST School. This was followed by brainstorming and group discussions to arrive at an optimal design concept that addresses our

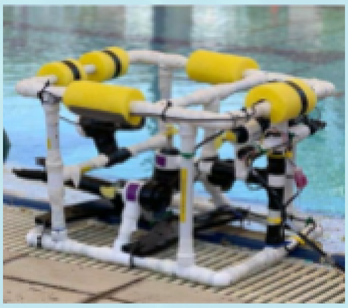


Figure 3: New frame design for competition

goals and available resources. The team's hard work and dedication resulted in Tyrone, an underwater ROV explicitly designed to meet the requirements of MATE's proposal.

From the design perspective of the frame, the development of the frame involved several changes throughout this year's program. In the early stages of the timeline, the team used a completely different approach to the frame design compared to the one currently used at today's International 2023 MATE ROV competition. A drastic improvement was also made while preparing for the regional competition. The mechanical and electrical engineers initially discussed incorporating all essential components within a frame that permits excellent maneuverability. Although this has remained the focus over the entire course of the frame's design, the design itself has shifted from what used to be a pyramid design to now a much more efficient product.

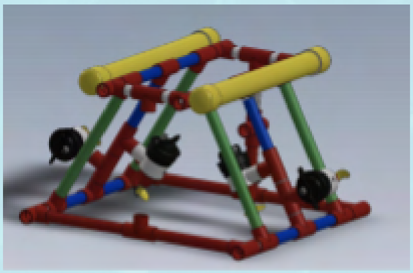


Figure 4: Initial frame design selected for competition

The changes made to the frame, such as the cuboid design used for the regionals, were imperative to reach the team's objective of completing the tasks to a successful standard. In Figure 3, a major change in terms of shape can be observed, as well as additional elements such as floats to increase maneuverability and buoyancy when tackling the underwater tasks.

As shown in Figure 4, the early stages of brainstorming the frame design were done through sketches. The frame builder communicated with the rest of the team, primarily the mechanical engineers, to draft a frame that best suited our expectations. After building the original pyramid structure and testing it at our school pool, the team decided it would be best to change the frame design. The frame designer drafted sketches and created the design for the new frame (Figure 5).

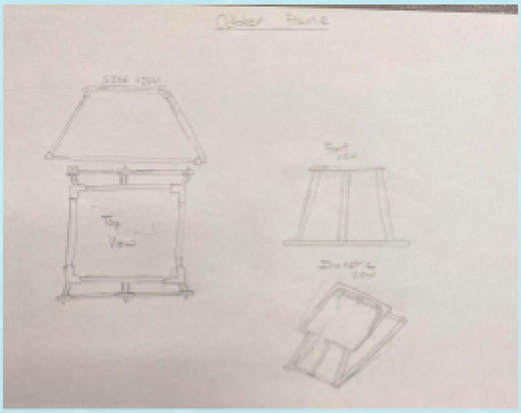


Figure 5: Initial frame design sketches

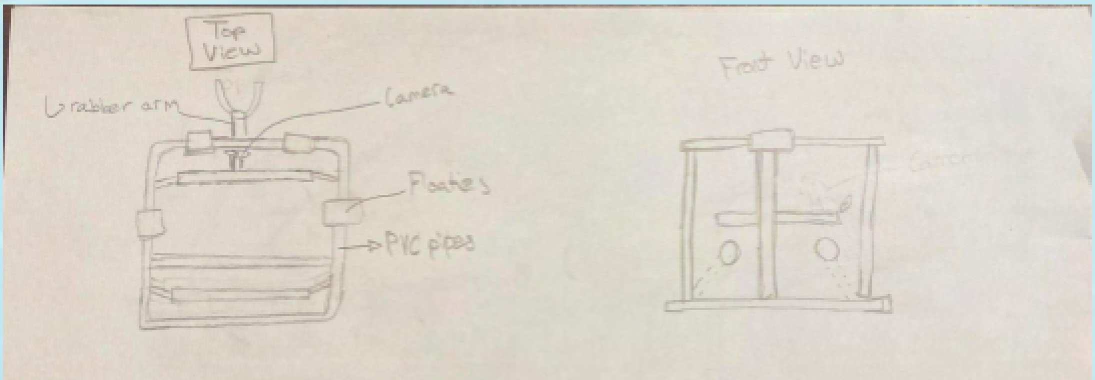


Figure 6: Revised sketch frame design (Regional)

Frame Safety Analysis

Safety remains one of the most critical focus areas at the TKS Reef Rovers. To ensure the safety and security of all team members and participants, the first step was to publish a safety checklist across our lab and working space which was easily accessible for everyone to refer to. The following steps ensured that the frame's design and other significant parts, like the control board, were safe to utilize. The frame constructor ensured zero spots in the body of the ROV, which could impose even slight safety threats. Some examples to guarantee the welfare of everyone working with the ROV were:

1. Complete sharp edges and corner sealing using multiple layers of tape, epoxy, and hot glue.
2. Bolts, screws, and other connectors were plugged correctly and connected to the frame of the ROV.
3. Guards on all motor propellers to provide additional protection to divers in the demonstration area.
4. All wiring in the frame's structure was securely fastened and protected from short circuits using heat shrinks, electrical tape, and hot glue.
5. PVC pipe connections throughout the frame were sealed entirely via countless layers of epoxy, tape, and glue

Potential improvements

In order to ensure the success of future projects, TKS Reef Rovers and the frame design engineer aim to make worthy changes to the frame in the coming years. Some of these changes include:

1. Change of material to options such as carbon fiber, fiberglass, steel, etc. This will help in producing a sturdier, more buoyant, and maneuverable frame body when performing tasks.
2. Reflecting on task performance as a whole to make more tailored adjustments to the frame in order to meet the requirements of specific tasks (Could also include changes to components part of the frame, such as grabber arm, motors, etc.)

Mechanical Documentation

Motors (Propulsion Systems).

Over the last several months, we tested several different motor placements. After several trial-and-error attempts, we found that placing two motors on the inner sides gave us the power to have a stable surge motion and move forwards and backward.

The team discovered that the surge motors could provide a turn motion and decided upon having one pitch motor rather than two. This cut both the weight and costs of the robot. After trialing the robot, we found that one motor in the center of the ROV would give us enough heave to both sink and lift the ROV. This was because the flotation devices made the ROV's weight neutral. Four motors were used, giving the robot the propulsion to complete the required tasks.

Grabber Arm

Another important step was to install the grabber arm. The placement of the grabber arm was decided by analyzing the type of tasks the robot would perform and determining where the grabber arms needed to be to complete each task. For example, we knew that the grabber arm would have to be close to the camera to ensure that the pilot could see which direction to steer it in, to complete tasks.

The grabber arm also had to be in a position where it could successfully grab, pull, or move any required materials without interfering with another element of the robot, such as the motors. After taking each of these factors into careful consideration, we decided that the optimal placement of the grabber arm was in the front of the frame and directly below the camera. This decision also affected the structure and overall build of the PVC frame, as it defined where each PVC support beam would be placed.

Flotation

Another vital element that had to be considered was the orientation and placement of the flotation devices that would be applied to ensure that the ROV was buoyant. The team decided that a satisfactory flotation device could be pool noodles. Once the frame was fully built, the pool noodles were cut into lengths of 12 centimeters, then attached to the PVC Frame. After testing the buoyancy and flotation of the robot, we noticed that the robot would not sink into the water. Several other pool noodle lengths were tested and modified, until we realized that rather than having all of the pool noodles as the same length, multiple pool noodles of different lengths could be used. In the end, a final consensus of 4 centimeters, 10 centimeters, and 12 centimeters. The mechanical engineers ensured that the pool noodles were only placed at the top of the ROV, and that thicker sections of pool noodles were used to support heavier sides of the robot.

The flotation was also relevant in the case of emergency situations. For example, in a real life scenario, if the tether were to snap, removing connection from the control panel and the robot, the flotation devices would ensure that the robot floated to the top of the water surface, rather than getting lost within the body of water.

ROV Dimensions

Length: 61cm
Height: 37cm
Width: 41cm
Weight: 6.7 kg

Here are some of the implication from the dimensions listed above:

- Size: The dimensions of the ROV can affect its ability to navigate in different underwater environments and complete specific challenges. For instance, a smaller ROV with a size of 18.41 cm × 29.50 cm × 33.50 cm may be more suitable for exploring confined areas or performing delicate tasks.
- Weight: The weight of the ROV can affect its stability, buoyancy, and power requirements. A lighter ROV may be more agile and require less power to move around, but may also be more susceptible to currents or waves. A heavier ROV may be more stable and have a higher payload capacity but may require more power to operate.
- Maneuverability: The size and weight of the ROV can also affect its maneuverability and ability to perform specific tasks underwater. For example, a larger ROV may require more

thrusters or more precise control to navigate through tight spaces or perform intricate maneuvers.

- Payload capacity: The size and weight of the ROV can also affect its ability to carry sensors, cameras, and other equipment for underwater exploration and research. A larger or heavier ROV may have a higher payload capacity and be able to support more sophisticated instruments and tools.

Overall, the measurements of an ROV can have significant implications for its design, performance, and suitability for specific underwater challenges. The size, weight, and maneuverability of the ROV should be carefully considered in relation to the tasks it needs to perform and the conditions it will encounter.

Camera and Placement

The robot's PVC frame would house the camera, which would be placed inside a cylindrical waterproofing case. To prevent water leakage through the cable hole, epoxy resin was lined around the cable hole. To ensure that the grabber arm could be seen while the pilot was directing it, the camera was placed at a -45° angle, and pointed directly at the grabber arm.

Improved navigation: A camera on an ROV can help operators navigate in tight or confined spaces, such as underwater caves or shipwrecks

1. Increased safety: A reversing camera can help eliminate blind spots and prevent accidents while backing up
2. Protection: A parking camera can detect movement or bumps while the ROV is parked and automatically start recording, providing evidence in the event of damage or accidents.
3. Efficiency: The camera can provide critical data and visual feedback, allowing operators to complete missions more efficiently

Overall, using a parking camera on an ROV can increase safety, efficiency, and protection while navigating underwater environments.

Tether Protocol

The tether connected the robot to the power box, which transmitted electrical pulses and data between the controller and the robot's. The tether required two wires per motor; one would carry the electrical pulses to the motor, and the other would carry those pulses back. The H.M.S. Tyrone consisted of four motors, and therefore eight wires. A camera was also present within the robot, which required an extra camera cable, containing additional wires to power the camera and for the video signals it was able to produce.

Another issue that was taken into consideration was the length of the tether. More energy and electricity is required to be transmitted through longer tethers, while less electricity is needed for shorter tethers. Therefore, as the length of the tether was increased, the amount of voltage that reached the robot gradually decreased. Less voltage can result in delayed turns, thrust, and overall performance. After considering this, the team decided that a tether length of 12 meters was suitable.

Frame Safety Analysis

Sharp edges and corners were sealed using multiple layers of tape, epoxy, and hot glue. Bolts, screws, and other connectors were plugged correctly and connected to the frame of the ROV.

Guards on all motor propellers to provide additional protection to divers in the demonstration area. All wiring in the frame's structure was securely fastened and protected from short circuits using heat shrinks, electrical tape, and hot glue. PVC pipe connections throughout the frame were sealed entirely via countless layers of epoxy, tape, and glue.

Testing

Position 1

Motors

- 2x Surge Motor
- 2x Heave Motor
- 0x Sway Motors

Flotation

- 2000 cm^3

Table 1 : Maximum Speed and Thrust for Each Degree of Freedom

Direction	Speed (km/h ±0.05)	Thrust (kg ±0.05)	Drag (kg ±0.05)
Forward	0.784	0.500	2.5
Backward	0.786	0.400	2.5
Up	0.784	0.300	4.6
Down	0.784	0.500	4.6
Left	0.786	0.500	2.8
Right	0.784	0.600	2.8

Position Description:

Utilizing two heave motors and two surge motors, (and excluding sway motors) offered several advantages to our robot. Primarily, heave motors provided vertical movement, which aided throughout tasks such as data collection.

The surge motors were used for forward and backward movements, allowing the ROV to travel from region to region. Two surge motors offered stability and control within the ROV, enabling precise movement and the ability to navigate through currents and waves.

Sway motors were excluded from the robot, as they were not vital in completing the task. Additionally, including sway motors would have redundantly increased the complexity and cost of the robot. The absence of sway motors made the robot simple, lightweight, and easier to control. Overall, it was proven that only two heave motors and two surge motors were needed to produce an underwater ROV which

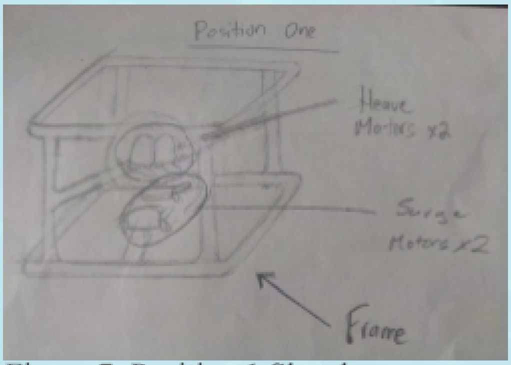


Figure 7: Position 1 Sketch

was able to perform multiple tasks with ease and efficiency (underwater research and exploration, maintenance, mapping, inspection, etc).

Position 2

Motors

- 1x Surge Motor
- 2x Heave Motor
- 1x Sway Motors

Flotation

- 2000 cm^3

Table 2: Maximum Speed and Thrust for Each Degree of Freedom

Direction	Speed (km/h ±0.05)	Thrust (kg ±0.05)	Drag (kg ±0.05)
Forward	0.974	0.600	2.5
Backward	0.975	0.600	2.5
Up	0.973	0.500	4.6
Down	0.970	0.600	4.6
Left	0.972	0.500	2.8
Right	0.970	0.600	2.8

Position Description:

The next motor positioning consisted of one heave motor, two surge motors, and one sway motor. This provided various advantages which were not available in the previous motor configuration. The sway motor allowed for lateral movement, which allowed the robot to move from side to side, with enhanced precision. While it did increase the complexity and overall cost of the robot, adding sway motors increased the amount of control that the pilot had over the robot.

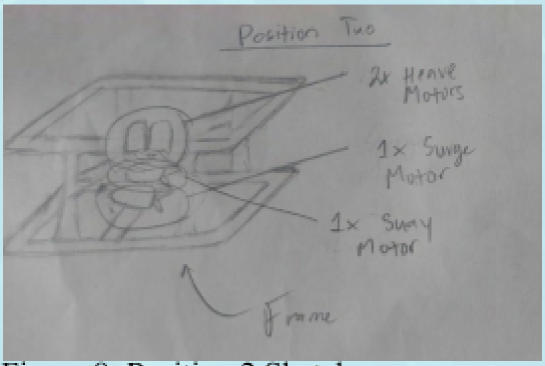


Figure 8: Position 2 Sketch

As a whole, this configuration provided excellent speed, maneuverability, and control, allowing the ROV to travel through various underwater environments and perform complex tasks with ease. The addition of the sway motor provided additional flexibility in the system, giving the robot the ability to move in three dimensions with a high degree of control. However, it is essential to consider the added complexity and cost of incorporating more motors into the system when designing and building the robot.

Position 3

Motors

- 2x Surge Motor
- 1x Heave Motor
- 2x Sway Motors

Flotation
- 2000 cm^3

Table 3: Maximum Speed and Thrust for Each Degree of Freedom

Direction	Speed (km/h ±0.05)	Thrust (kg ±0.05)	Drag (kg ±0.05)
Forward	0.878	0.900	2.5
Backward	0.874	0.900	2.5
Up	0.876	0.400	4.6
Down	0.875	0.600	4.6
Left	0.878	0.500	2.8
Right	0.874	0.600	2.8

<u>Position Description:</u>

The final configuration consisted of one heave motor, two surge motors, and two sway motors. The two surge motors enabled the robot to quickly travel forwards and backwards, and quickly change direction. Incorporating two sway motors allowed for additional lateral movement, resulting in increased precision and control while maneuvering and performing tasks. This made it easier to navigate through tight spaces or complete specific tasks that required precise movement. The robot could now move in any lateral direction, making it easier to perform tasks such as inspection, mapping, underwater research, and maintenance with precision and stability.

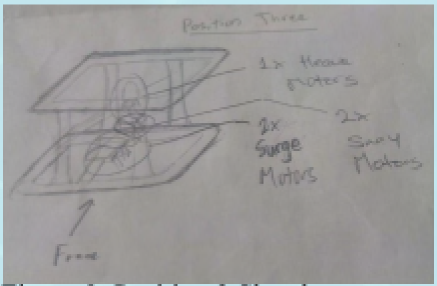


Figure 9: Position 3 Sketch

Overall, this assemblage of motors gave the robot a high degree of mobility, and flexibility in all three dimensions, aiding it to easily perform complex tasks. This made it an ideal choice for underwater operations which required complex movement and precise control. However, it is also important to consider that the addition of two sway motors increases the complexity and cost of the system, and requires additional sensors and control systems, to ensure that all the motors successfully work together to deliver optimal performance.

Buoyancy:

Table 4

	Flotation result (Positive +, neutral /, negative -)				
Flotation (cm^3)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0	-	-	-	-	-
500	-	-	-	-	-
1000	-	-	-	-	-
1500	-	/	-	/	-
2000	/	-	/	/	-
2500	+	/	+	+	/
3000	+	+	/	+	+

Buoyancy Explanation:

In order to ensure that the ROV was buoyant, 2000 cm^3 of foam was used. After carrying out trials with different amounts of foam, it was found that 2000 cm^3 was the optimal amount. Below are descriptions of the robot when different volumes of foam were implemented.

- 0 cm^3: Without any foam, the ROV would sink and not be able to move around underwater.
- 500 cm^3: This amount of foam did not provide enough buoyancy to keep the ROV afloat and therefore caused it to sink.
- 1000 cm^3: This did not provide a substantial amount of buoyancy; the ROV was only able to float some of the time, causing it to sink and move uncontrollably.
- 1500 cm^3: This amount of foam provided enough buoyancy to keep the ROV afloat, but was stable enough to grant the pilot complete control over the robot.
- 2000 cm^3: This amount of foam provided enough buoyancy to keep the ROV afloat and stable underwater.
- 2500 cm^3: Using 2500 cm^3 of foam resulted in too much buoyancy, making it difficult to control underwater.
- 3000 cm^3: This amount of foam made the ROV too buoyant and unstable, making it difficult to control and maneuver underwater.

There are several types of foam that can be used for ROV buoyancy, including syntactic foam and polyurethane foam. These foams are designed to provide buoyancy and resist hydrostatic pressure underwater, making them ideal for use in underwater robotics applications

Final Design Testing:

Direction	Speed (km/h ±0.005)	Thrust (kg ±0.05)	Drag (kg ±0.05)
Forward	0.97	0.900	2.5

Backward	0.98	1.000	2.5
Up	0.52	0.200	4.6
Down	0.25	0.700	4.6
Left	0.57	0.700	2.8
Right	0.57	0.700	2.8

Sample Calculations:

Speed: m/s x 3600/1 x 1km/1000

Figure 10: Device used for thrust

Challenges

- The mechanical aspects of the creation of the robot led to a variety of challenges, which required a large amount of troubleshooting.
- The first challenge was deciding upon a frame structure. In order to do so, the mechanical engineering team drafted their ideas for frame designs. The mechanics then decided upon a final design. It was then modified and altered to fit the required specifications, and to be able to complete the necessary tasks.
- Another challenge that emerged was deciding which types of motors (surge, heave, and/or sway) would be incorporated into our design, and how many of each would be used. To determine this, multiple frames were designed, each of which could accommodate different amounts of motors, and had different locations that the motors would be placed based on the type of motor. To determine which design would be used, the rovers were tested and analyzed, until a consensus was reached.
- During the initial stages of testing the robot, there were several issues with the buoyant balance of the robot. This had significant effects on the steering ability and control over the robot. To overcome his challenge, a grabber arm was added. This helped to straighten out the robot's buoyancy.
- The mechanical engineers mitigated these issues by adjusting the size and positions of the floats. The frame was also redesigned several times, to allow for smooth movement without unexpected tilts or imbalances.

Electrical Documentation

<u>Overview</u>

The control system and on-board electronics are designed to be integrated reliably, and to be non-critical to the ROV in the case of an area-specific failure. Wire points are soldered and waterproofed with several layers of safety. Power is safely managed with fuses in two places, and is controlled for critical components such as the Raspberry Pi using boost converters.

<u>Control system</u>

The robot functions off a heavily customized and modified Triggerfish control box. The main control functionality is all above-surface, and communicates with the ROV via a tether. The main power is from a single external power source of 12V, which directs to the Triggerfish control board and is distributed to the power distribution module. The tether and motor controllers receive 12V, and the Raspberry Pi receives a 5V 3A power supply converted by the Ubec boost converter.

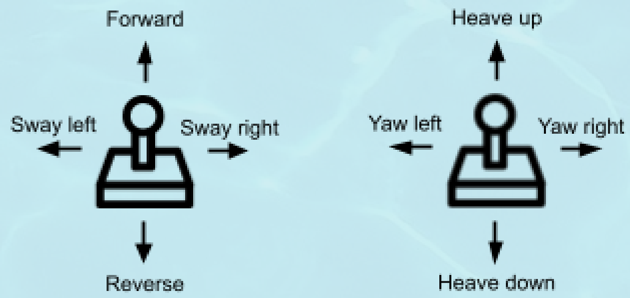


Figure 11: Control stick mapping

We replaced the motor controllers with Pololu MD03A which we found were significantly more reliable than the original Sabertooth controller. We implemented a Raspberry Pi 4 board which we were able to program and connect using the GPIO pins to control the onboard motors. The Raspberry Pi 4 reads and maps inputs from a wireless mouse and a wireless controller to the motors. The motor control outputs from the Raspberry Pi go through the two motor controllers which then connect to the motors. The grabber arm connection is directly connected to the Raspberry Pi via the tether.

<u>Onboard Components</u>

The surface control delivers power and control to the ROV using a 12 meter tether. The tether supplies 12V power. The motors (*fig4*) each receive ground and two 12V inputs. The camera is a repurposed rear-view parking camera (*fig5*), which has an analogue output connected using RCA connectors. The grabber arm is a BlueROV Newton Subsea Gripper (*fig6*), and is powered and controlled with 12V and ground connections. The wire connections are waterproofed using heat-shrink waterproof solders, silicon covering and shrink-wrap covers. The camera and grabber arm connections are waterproofed by epoxy and hot glue. All wires route along the frame and merge into the tether.

Component (hardware/software)	Quantity
Triggerfish motors	4
Triggerfish tether (modified)	12m
Triggerfish control kit	Inclusive
Pololu MD03A motor controller	2
Raspberry Pi 4 model B+	1
ONOO 16A power distribution module	1
Ubec 5V 6A boost converter	1
FPV 5” battery-powered monitor	1
Logitech wireless mouse	1
Logitech F710 wireless controller	1
Rear-view camera	1


Figure 12: Motors


Figure 13: Camera

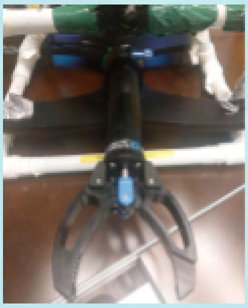


Figure 14: BlueROV gripper

Testing & troubleshooting

We test the surface components regularly using LEDs connected directly to the motor controllers to visually see the motor outputs. We test soldered connections using a multimeter after every solder. We also perform full-system pool tests when adding new features or changes to check that all connections work as expected. All testing is done with two fuses in place in the surface control, located at points to safely break before any components are damaged.

We had issues with the original sabertooth motor controllers, which we then replaced with Pololus which worked more reliably. Through the process, we’ve burnt a Raspberry Pi board by accident, most likely with static discharge, so we had to replace it with a new one which set us back. From then on we observed more safety measures when handling sensitive boards.

For safety, we have two fuses, and we calculate the capacity of each with the following:

Motors: 4 x 3.4A = 13.6
Arm: 0.28A = 0.28
Other (board overall): 1.07
Total: 14.95A * 120% = 17.94A
Fuse capacity: 20A

Software

Overview

The software is based on the Raspberry Pi 4 on the surface, written in Python 3.8. We used the wireless Logitech F710 handheld controller via USB attached to the Raspberry Pi, and we used PyGame to read controller inputs. Using a PWM signal to control the speed of the motors, we were able to map the joystick controls to the motor movements. Because of using a PWM signal, we could reliably allow incremental speeds for precise movements.

We made contextual joystick mapping, so moving the left joystick vertically forward, for example, would run both forward-facing motors. We allowed for dynamic controller connecting and disconnecting so in any case of an issue with the controller, the robot won't behave unexpectedly. The grabber arm uses a servo controller library, as the arm behaves similarly to a servo, and we were able to map a button on the joystick to toggle the grabber.

The script has to be run via the Raspberry Pi's operating system using a mouse, which we're able to view on the monitor in the control box via an HDMI cable. On the monitor, we can switch between the HDMI view and the camera's view easily.

Testing & Troubleshooting

Initially, through trial and error we were able to map the motor directions successfully. Visually we checked every movement axis and combination of movements to see if they would have an expected result. We later put the robot in the water in one of our main tests, and the pilot checked if the controls moved the robot in the expected directions.

Getting the grabber arm to open and close had several issues, but with time we decided to use a servo library which solved the issues.

Challenges

The software served its purpose and ran reliably on the competition day without halting or failing unexpectedly. However, the main issues are the setup to run the software, as well as the grabber arm having unexpected jittering when opening or closing.

Safety

Our Philosophy

MATE prides itself on having its focus on safety for all participants and organizers. Here at *Reef Rovers* we take safety seriously. We make sure that all our engineers, members and head officers are protected and satisfied so that they can produce the highest quality work possible. We ensure that our members are able to master their trades and show their talents on the worldwide stage, in a safe environment. Our team follows the Job Safety Analysis and Lab Safety as closely as possible so that we can have a safe launch, recovery and waterside operations at all times, under and above water.

Safety Protocols

Reef Rovers main concern is its members safety and wellbeing. Due to this specific, personal protective equipment is in order for all members to wear. This consists of glasses, shoes/boots, lab coats and gloves at all times. In the lab environment it is also needed for there to be a Fire extinguisher, Eyewash station and a first aid kit in easy and quick access areas. All danger and caution areas are to be highlighted with fluorescent and eye catching symbols and stickers. All team members are expected to follow lab protocols and procedures without any room for error. Professionals using electrics are expected to find and prevent any electrical hazards by using the proper procedures using the proper materials and tools.

The body shape and frame is developed specifically to be as solid and rigid as possible, thus maximizing safety and efficiency of the ROV. All the wires, bolts, connectors and sealant are ensured to prevent any problems that may occur underwater. The thrusters used on the HMS Tyrone are all surrounded by a thruster guard to prevent all blade injury and any items getting stuck on the thrusters. All the mesh guards completely encircle each thruster and all guards meet the IP-20 standards which means that the size of mesh must be >12.5mm. All electric components on the HMS Tyrone are protected by placing them into a plastic transparent pipe sealed by epoxy and superglue, all being supported by electrical tape and duct tape. The plastic used in the pipe is able to withstand depths of up to 8 meters. Cables for the camera and the tether are all sealed using a piece of plastic sealed by rubber, epoxy and superglue to both waterproof and prevent the cables from and possible shorting and water damage. The ROV is able to be carried by its frame and the tether to prevent it from slipping and easy carry, everything is connected and fastened to prevent any sharp edges and to prevent from the ROV having a chance to both fall apart and break.

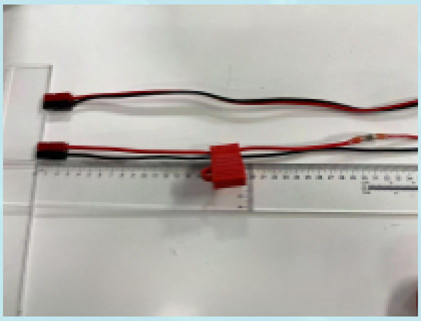


Figure 15: Waterproofed Powerpoles

Corporate Responsibility

The TKS Reef Rovers deeply values giving back to the community and providing everyone with the opportunity to learn and grow in the field of robotics. We hope to give younger students the ability to express their ideas and grow their creativity.

Mentoring

In order to manifest these values, we participated in mentoring younger students in the community in the field of robotics. Our mechanical engineering head shared his expertise with the elementary school students in our area. He assisted them in participating in the scout sector of the MATE ROV competition.

Furthermore, our team assisted kindergarten students by showing them the ROV and how it functions. We explained in depth about how the competition worked and how underwater ROVs are used in real life to solve global issues. The children were evidently inspired by the competition and it is clear that the future generations have much to hold in the field of robotics and innovation.

Display

We also held an outdoor pool demonstration to display our work to the members of the community. This allowed us to inspire other people to pursue robotics, while also providing us with the perfect opportunity to gain feedback from the wider community. This

feedback was so valuable, as it allowed us to see our project from a different perspective, rather than just someone who is a part of the company.

Overall, this display was the perfect opportunity to gain outreach for our company while also gaining valuable feedback from the community.

Accounting

Budget Planning and Follow Through

Before investing any large funds into this project, we started by creating a rough budget sheet to estimate the total costs. This included all the parts of the ROV as well as the trip to the international competition. The regional competition did not include any travel costs as we were the hosts. After finalizing our budget sheet by researching the exact cost of certain products, such as the TriggerFish ROV Kit, we presented the costs to the The KAUST Robotics, Intelligent Systems, and Control Lab (KAUST RISC Lab) and the Coastal and KAUST Marine Resources Core Lab (KAUST CMOR Lab) to sponsor the necessary equipment. As we made sure to get exact costs of all the equipment we planned to use, the budget was very accurate, with some room to spare, as seen in the table below.

Use of Funds

Throughout the course of this project, we ensured that the funds were used effectively. An example of this is that when we were conducting motor placement tests, we did not secure the motors fully, meaning they could be removed if necessary without any financial damage. All of our major equipment was sponsored by the RISC lab and CMOR lab, meaning that we had to be responsible with our spending and not purchase unnecessary equipment. In one scenario, we accidentally short-circuited a raspberry pi. While this was a setback, we learnt from our mistake and made sure that all future circuits were made in a secure and safe manner.

Cost Breakdown

Date	Type	Category	Expenses	Description	Budget	Cost	Cumulative Cost
18 Feb	Sponsored	Hardware	PVC	PVC Pipes and Connectors	$300.00	$210.00	$210.00
18 Feb	Sponsored	Hardware	Power Supply	Provides power for the ROV to function	$50.00	$50.00	$260.00
18 Feb	Sponsored	Electronics	Fuse	15A fuse	$15.00	$10.00	$270.00
28 Feb	Sponsored	Electronics	Triggerfish Set	ROV Kit with Thrusters and Tether	$850.00	$850.00	$1,120.00
13 Apr	Sponsored	Hardware	Jumper Cables and	Connected all parts of the ROV	$20.00	$15.00	$1,135.00

			Wires				
4 May	Sponsored	Electronics	Raspberry Pi	Used to program motors/arm	$250.00	$250.00	$1,385.00
5 May	Sponsored	Electronics	Pololu Motor Controller	Allow variable speed and direction control	$100.00	$100.00	$1,485.00
5 May	Donated	General	Shirt Stickers	Shirt stickers	$10.00	$0.45	$1,485.45
7 May	Purchased	General	Electric Tape	Secures components safely	$5.00	$2.50	$1,487.95
7 May	Sponsored	Electronics	Power Distribution Module	Allowed to distribute power throughout components	$50.00	$20.00	$1,507.95
7 May	Sponsored	Hardware	Grabber Arm	BlueRobotics Newton grabber arm	$600.00	$590.00	$2,097.95
8 May	Sponsored	Hardware	Frame	BlueRobotics BlueROV2 frame	$390.00	$390.00	$2,487.95
7 May	Sponsored	General	ROV Stickers	Thermal-printed Stickers	$10.00	$0.35	$2,488.30
7 May	Sponsored	Hardware	Heat Shrinks	Secures wire ends	$10.00	$5.00	$2,493.30
8 May	Sponsored	Hardware	Monitor	Portable monitor	$200.00	$130.00	$2,623.30
9 May	Sponsored	Hardware	Controller	Wireless Logitech F710	$50.00	$80.00	$2,703.30
9 May	Sponsored	Hardware	Mouse	Wireless Logitech mouse	$50.00	$30.00	$2,733.30
9 May	Sponsored	Hardware	Camera	Parking camera	$25.00	$10.00	$2,743.30
9 May	Sponsored	Hardware	Camera Cover	Acrylic tube	$10.00	$9.00	$2,752.30
9 May	Sponsored	General	Zip Ties	Holds wires out of motor's way	$5.00	$4.00	$2,756.30
10 May	Sponsored	Hardware	Breadboard	Extends signals	$10.00	$6.00	$2,762.30
26 May	Sponsored	Travel	Hotel/Airbnb	Accommodation in Longmont, CO, USA	$10,000.00	$10,000.00	$12,762.30
30 May	Sponsored	Travel	Flights	Flights to and from Denver airport	$35,000.00	$31,000.00	$43,762.30
18 Jun	Sponsored	Travel	Taxis	Taxis to and from airport and venue	$1,000.00	$800.00	$44,562.30

Sponsored value	$44,559.35
Donated value	$0.45
Purchased value	$2.50
Total Value	$44,562.30
Budget Value	$49,010.00

Acknowledgements

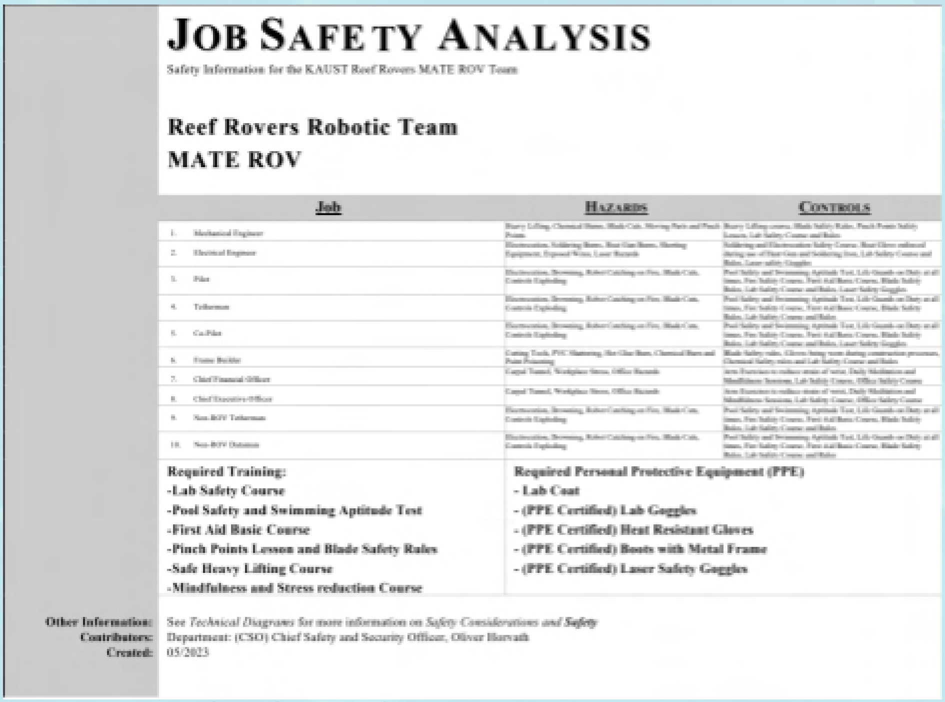
This year was the very first year TKS attended and hosted the MATE ROV regional competition, and we are aware of the fact that there is much uncertainty with backing and supporting such a new and inexperienced team. However we are ever grateful for the people at TKS and KAUST core labs and RISC labs for supporting us with equipment and for helping us attend and organize such a prestigious event.

We cannot give more thanks to our mentors who helped us on every step of the way. Majed and Nawaf gave us insightful feedback throughout the preparation of the ROV and their intuition and knowledge was invaluable. With their help we were able to build a working ROV and we were able to win the regional tournament, so because of this we are ever grateful for hardworking and amazing mentors Majed and Nawaf.

Lastly we would like to acknowledge MATE and TKS for both organizing and hosting this event, we believe that it is a great opportunity to teach STEM skills and we believe that because of their joint efforts there will be many more successful events in the coming years. Thank you all for your support and help.

Appendix

Appendix A: Safety Analysis & Checklist



JOB SAFETY ANALYSIS

Safety Information for the KAUST Reef Rovers MATE ROV Team

Reef Rovers Robotic Team
MATE ROV

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, Laser Hazards	Soldering and Electrocution Safety Course, Heat Glove enforced during use of Heat Guns and Soldering Iron, Lab Safety Course and Rules, Laser safety Goggles
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, Laser Safety Goggles
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, Laser Safety Goggles
6. Frame Builder	Cutting Tools, PVC Shattering, Hot Glue Burns, Chemical Burns 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 [illegible]	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
- (PPE Certified) Laser Safety Goggles

Other Information: See *Technical Diagrams* for more information on *Safety Considerations and Safety*
Contributors: Department: (CSO) Chief Safety and Security Officer, Oliver Horvath
Created: 05/2023

Figure 17: Job Safety Analysis

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.		

Figure 18: Safety Checklist

2023 MATE ROV COMPETITION
UN Decade of the Ocean: Diving In to Inspire Solutions Because Together Opportunity Runs Deep
PIONEER/RANGER CLASS Non-ROV Device Power Specifications and Independent Sensors SAFETY CHECK LIST. Companies must bring this check list with them to their safety inspection.

In 2023, both the vertical profiling float and a powered fish fry release container qualify as a non-ROV device. The fish fry release container may be unpowered as well.

	ELEC-NRD-001: Non-ROV devices **cannot** be powered from the surface. Power is limited to 12 VDC maximum and 6 amps maximum.
	ELEC-NRD-002: The device may not utilize cameras. Thrusters are allowed for the float (but not the release container).

	ELEC-NRD-004: Onboard power is allowed for non-ROV devices. If onboard batteries are being used, the following specifications must be met:
	• Batteries must be primary (non-rechargeable).
	• AAA, AA, A, A23, C, D or 9V alkaline batteries are allowed. Alkaline batteries only.
	• Batteries are mounted in a manner that they are not loose inside the container.
	• A fuse (7.5 amps max) must be installed within 5 cm of the battery positive terminal.
	• The enclosure housing must be designed so that it will open if the pressure inside the housing is greater than the outside pressure
	• Any pressure relief plug MUST be at least 2.5 cm in diameter.
	• The enclosure housing must be designed so that it will release pressure if pressure inside the housing is greater than the outside pressure. Under no condition should the housing be built with fasteners to hold the device together if there is no pressure release valve.
	ELEC-NRD-005: An SID must be submitted for a Non-ROV device that uses electrical power.

	Independent Sensors
	ELEC-IS-001: Independent sensors must be powered from the surface; no onboard batteries are allowed.
	ELEC-IS-002: Companies may use USB to connect their sensor to a computer. Companies may also use surface battery packs (limited to 12 volts maximum) or the MATE supply to provide power for their independent sensor.
	ELEC-IS-003: The independent sensor may only contain the intended sensor; thrusters, cameras, or other systems MAY NOT be attached.
	ELEC-IS-004: Companies that use an independent sensor must provide a 3 amp (or less) fast blow fuse on the positive side of their connection.
	ELEC-IS-005: An SID must be submitted for an independent sensor that uses electrical power.

Figure 19: Specification Checklist

2023 MATE ROV Competition
Diving In to Inspire Solutions Because Together Opportunity Runs Deep
RANGER CLASS INITIAL SAFETY AND DOCUMENTATION REVIEW

Submission is on time, within the given size limit, uses the proper naming convention, is a PDF file, and is submitted with the other documents.

1	0	Technical documentation
1	0	Company spec sheet
1	0	SID(s)
1	0	Non-ROV device design specifications
1	0	Company safety review

SID

1	0	SID is 1 page in length and drawn with CAD (is not hand drawn)
1	0	SID shows a fuse and fuse uses a proper IEC, NEMA, or ANSI symbol
1	0	SID includes proper fuse calculations
1	0	SID is a higher level interconnection diagram, not component level electrical schematic

Non-ROV Device SID (vertical profiling float)

1	0	Each Non-ROV device SID is 1 page in length and drawn with CAD (is not hand drawn)
or		
1		Company safety review states they are not attempting the non-ROV tasks

SID fluid power

1	0	Fluid power SID is 1 page in length and drawn with CAD (is not hand drawn)
1	0	Fluid power SID uses industry standard symbols
or		
2		Company safety review states fluid power is not used.

Non-ROV device design documents (vertical profiling float)

1	0	Non-ROV devices are properly documented
or		
1		Company safety review states they are not attempting the non-ROV tasks

Company safety review (photos are required for each system)

1	0	ROV uses Anderson Powerpole connectors and has a properly sized fuse within 30 cm
1	0	Company safety review includes proper fuse calculations
1	0	Control box/console is neatly laid out and does not have exposed wiring
1	0	AC and DC are separated and identified in control box, or AC is not used
1	0	ROV has adequate ROV-side strain relief and pressure housings can withstand depth
1	0	All propellers are properly shrouded and protected to IP-20 standards
1	0	No sharp edges or dangerous components are seen on ROV

TOTAL POINTS:	

Company has passed fluid power quiz	Yes	No
Company is on approved laser list	Yes	No
Company is on approved pressure release valve list	Yes	No

Figure 20: Initial Review

Appendix B: ROV's SID

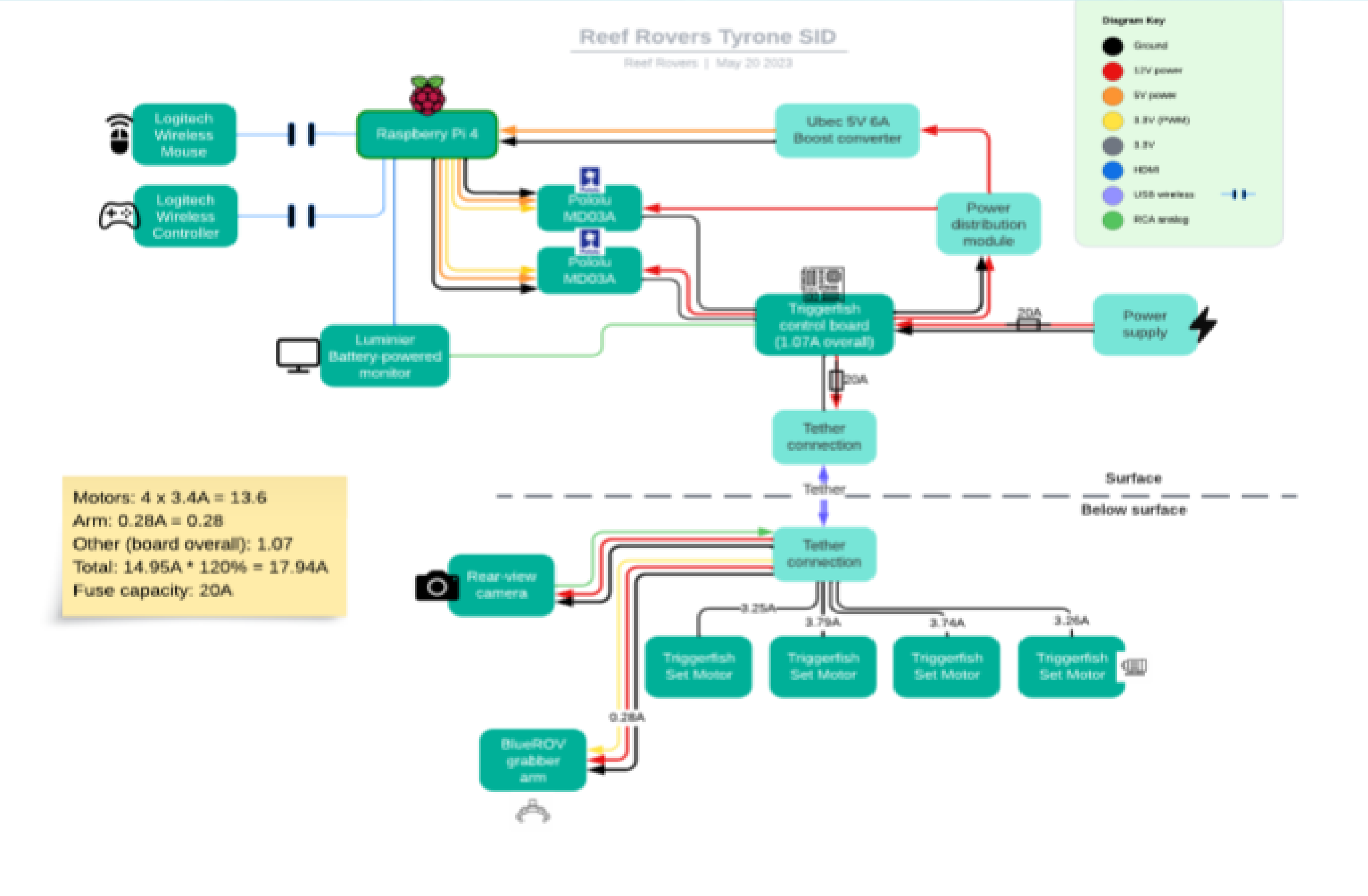


Figure 21: ROV's SID

Appendix C: Float's SID

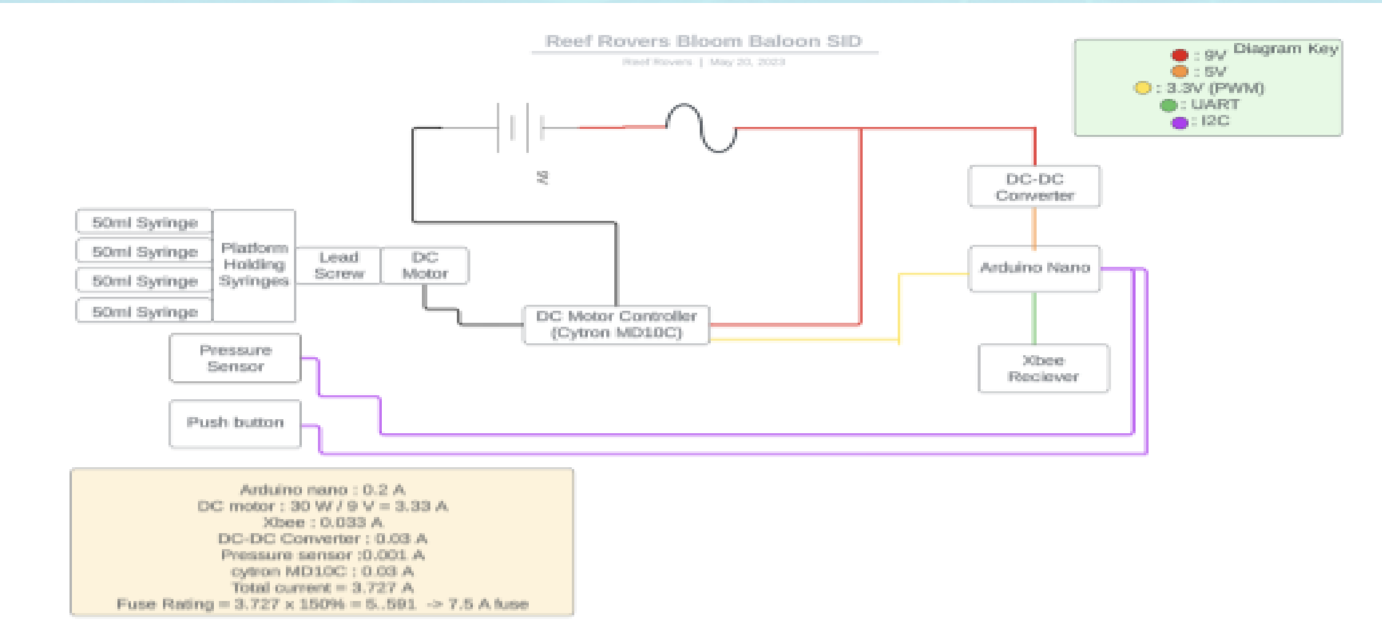


Figure 22: Float SID

References

Arduino - home. (n.d.). Arduino.Cc. Retrieved March 11, 2023, from https://www.arduino.cc/

Blue Robotics - underwater ROVs, thrusters, sonars, and cameras. (2020, January 7). Blue Robotics. https://bluerobotics.com/

Computer, electrical and mathematical sciences and engineering division. (n.d.). Edu.Sa. Retrieved March 26, 2023, from https://cemse.kaust.edu.sa/

Home. (n.d.). KAUST-CoreLabs. Retrieved April 4, 2023, from https://corelabs.kaust.edu.sa/

Personal cloud storage & file sharing platform - Google. (n.d.). Google.com. Retrieved April 4, 2023, from https://www.google.com/drive/

Raspberry Pi Foundation. (n.d.). *Teach, learn, and make with the*. Raspberry Pi Foundation. Retrieved May 11, 2023, from https://www.raspberrypi.org/

RISC lab. (n.d.). Edu.Sa. Retrieved May 11, 2023, from https://cemse.kaust.edu.sa/risclab

SeaMATE store. (n.d.). SeaMATE. Retrieved May 15, 2023, from https://seamate.org/

SID Creator. (n.d.). Slideshare.net. Retrieved May 21 ,2023, from https://www.slideshare.net/arneb/sid-creator

TKS kaust. (n.d.). TKS Kaust. Retrieved May 22, 2023, from https://tks.kaust.edu.sa/