CITYU HK
Underwater robotics

Hong Kong

CITYU FRONTEER
ROV

2024 MATE ROV TECHNICAL DOCUMENTATION

香港城市大學
City University of Hong Kong

CITYUHK UNDERWATER ROBOTICS

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ABSTRACT

CityU Underwater Robotics at the City University of Hong Kong (CityUUR) is excited to introduce *Fronteer*, our innovative remotely operated underwater vehicle designed for the MATE 2024 Explorer Challenge. *Fronteer* embodies our dedication to combating climate change and protecting marine environments. Created with our expertise and passion for underwater robotics, *Fronteer* integrates advanced concepts and professional knowledge, positioning it as a significant tool for ocean conservation. The vehicle features a new gripper design and an enhanced electronic system, improving its ability to complete tasks for the MATE 2024 competition. As we take on this challenge, *Fronteer* represents our mission and commitment to making a positive impact on our oceans' future.

Fig. 1 CityU Underwater Robotics 2024

COMPANY STRUCTURE

CityUUR operates with four departments: **Mechanical, Electronics, Software,** and **Public Relations** (**PR**). This straightforward yet robust organizational setup ensures optimal project management and development. Members are strategically allocated to departments based on their technical expertise and strengths. Each department is headed by an **engineer lead** who is responsible for overseeing project progress and ensuring efficient task allocation. The project is supervised by a dedicated **project manager** who closely monitors progress, resource distribution, budget adherence, and costs. Overarching direction and guidance for the entire company come from the CEO.

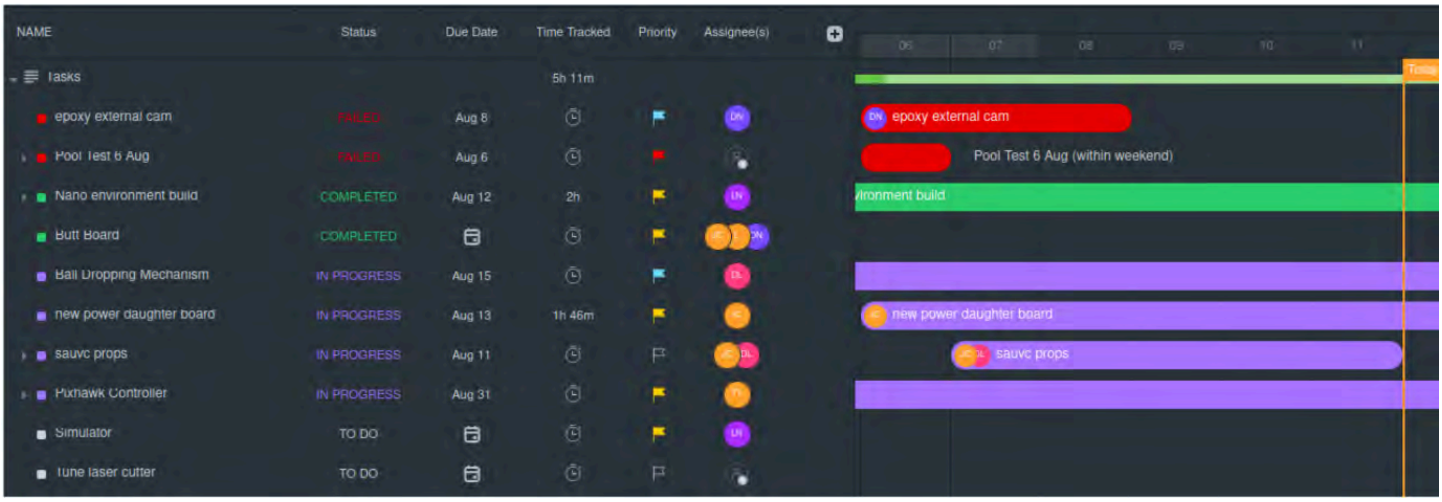
Team communication

To maintain cohesion and alignment with project goals, CityUUR conducts biweekly team meetings and weekly department meetings. These regular gatherings serve as platforms for reviewing progress, reflecting on performance, and collectively addressing any challenges. By fostering an environment of open communication and collaborative problem-solving, these meetings enhance overall productivity and synergy within the organization.

Fig. 2 Idea brainstorming during weekly meeting

Management Platform

CityUUR leverages various tools such as Google Drive, Discord, ClickUp, and a suite of self-hosted services including Wiki.js, NAS, Gitlab, and CVAT. These platforms streamline file storage, facilitate seamless communication, and enable efficient project and code management. The self-hosted infrastructure ensures remote accessibility, simplifies resource sharing, and supports automation of repetitive tasks like daily file backups, code CI/CD, and maintaining team office access logs.



NAME	Status	Due Date	Time Tracked	Priority	Assignee(s)
Tasks			5h 11m		
epoxy external cam	FAILED	Aug 8			DN
Pool Test 6 Aug	FAILED	Aug 6			
Nano environment build	COMPLETED	Aug 12	2h		LN
Butt Board	COMPLETED				
Ball Dropping Mechanism	IN PROGRESS	Aug 15			DL
new power daughter board	IN PROGRESS	Aug 13	1h 46m		
sauvc props	IN PROGRESS	Aug 11			DL
Pixhawk Controller	IN PROGRESS	Aug 31			
Simulator	TO DO				LN
Tune laser cutter	TO DO				

Fig. 3 ClickUp task interface

HackMD and Wiki.js serve as repositories for meeting notes and technical documentation, ensuring swift access to critical information for team members. Recognizing the importance of preserving institutional knowledge, CityUUR has dedicated significant effort to documenting past projects, particularly legacy machines. This proactive approach addresses challenges related to understanding design decisions and key Standard Operating Procedures (SOPs) from previous generations. Following a security review event prompted by the growing reliance on self-hosted services, the company implemented enhanced security measures including password updates, stricter firewall rules, automated file backup, and access control protocols. These measures aim to safeguard critical product data from cybersecurity threats.

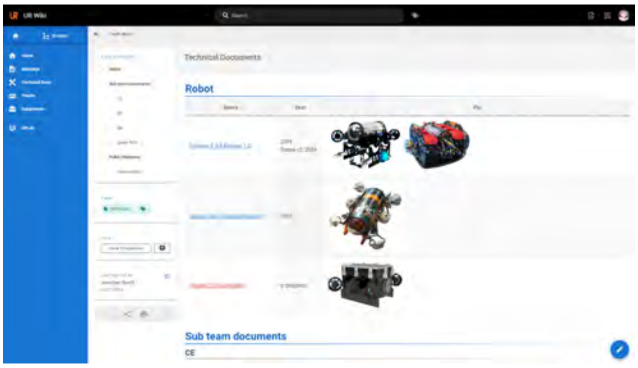


Fig. 4 Interface of the Wiki

Project Schedule

At the outset of each academic year, the CEO and department leads collaborate to establish a comprehensive schedule encompassing key events such as new member training, design and prototyping phases, testing and modification cycles, and report writing deadlines. This proactive planning ensures clarity regarding task timelines and expectations. Progress is regularly monitored and discussed during biweekly team meetings and weekly department meetings, allowing for timely adjustments and course corrections as needed.

Period	**Our Development Phase**
October 2023 to January 2024	Trained new members, reviewed our past ROV and its system, brainstormed, and researched new designs.
January 2024 to March 2024	Received the MATE documentation and started the design prototype.
March 2024 to Mid June 2024	Conducted in-house testing, modification, and pool testing.
End of April 2024	Regional MATE Competition.
Mid of June 2024	International MATE Competition.

Table 1 Develop Phase

Design Overview

Building on past experiences, our team improved *Fronteer's* design. Key updates include a new gripper and a compact, advanced electronic system, addressing performance issues and **enhancing flexibility, mobility, and stability**.

Dimensions (**LxWxH**)
46cm x 41cm x 33cm

Weight: 15.86 kg

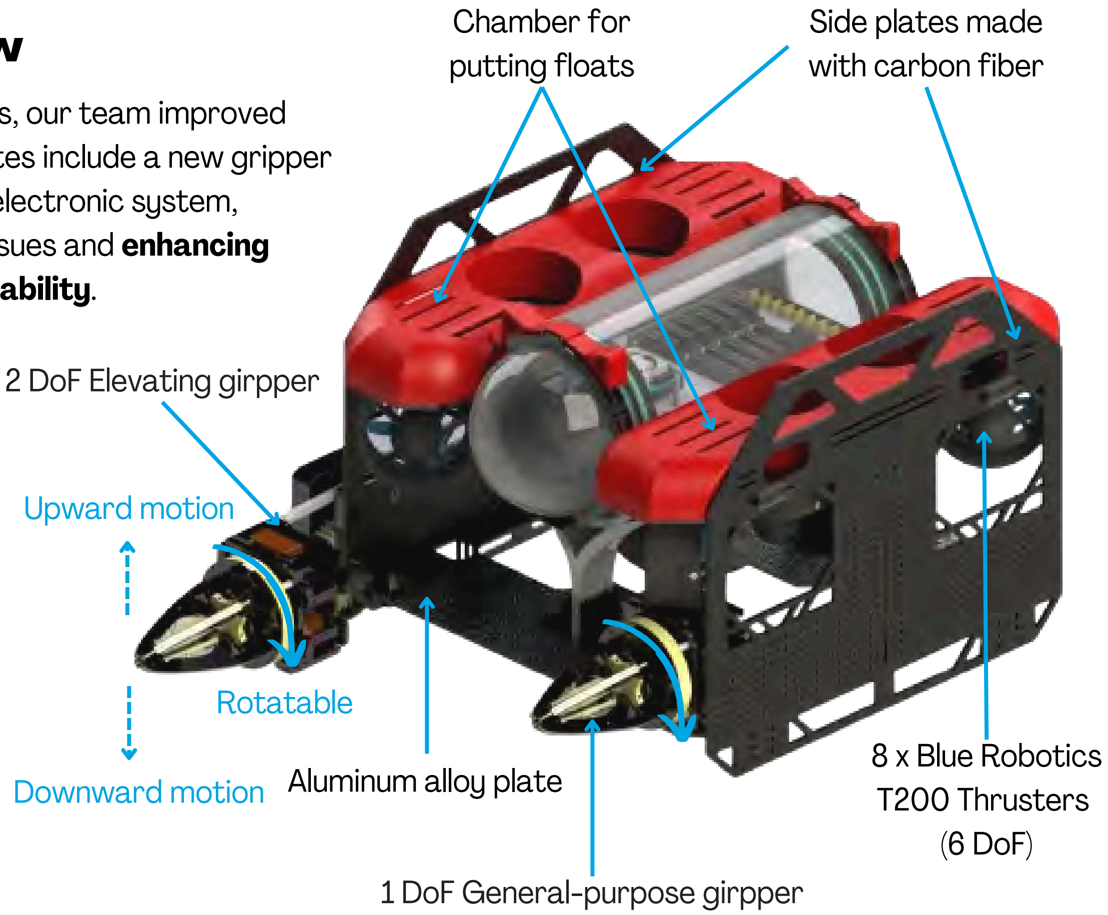


Fig.5 Top view of *Fronteer*

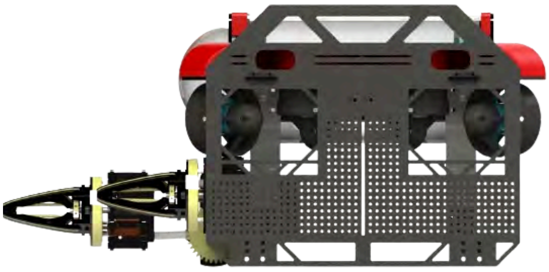


Fig.6 Side view of *Fronteer*

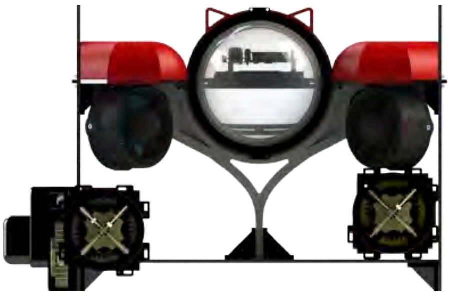


Fig.7 Front view of *Fronteer*

Design Process

Brainstorming was a crucial step in our project. Junior designers drafted initial designs and presented their ideas to senior engineers for peer review, fostering a collaborative environment that ensured innovation and feasibility.

Our methodology included sketching, printing, and examining each component to ensure design quality and eliminate flaws like sharp edges. After verifying each part, we assembled a simulated product, which served multiple purposes: aiding mechanical engineers with buoyancy estimation, assisting electrical engineers in wiring design, and enabling computer engineers to conduct unit testing.

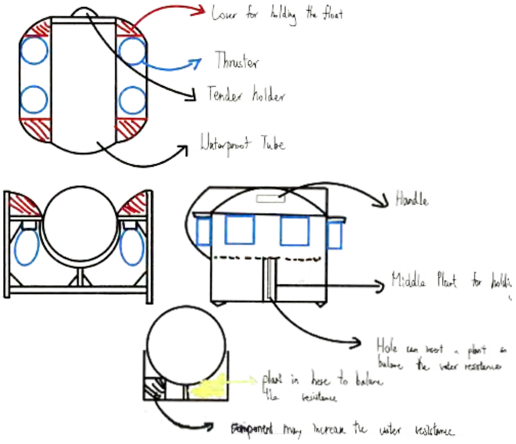


Fig. 8 Hand sketch of *Fronteer* at Brainstorming Stage

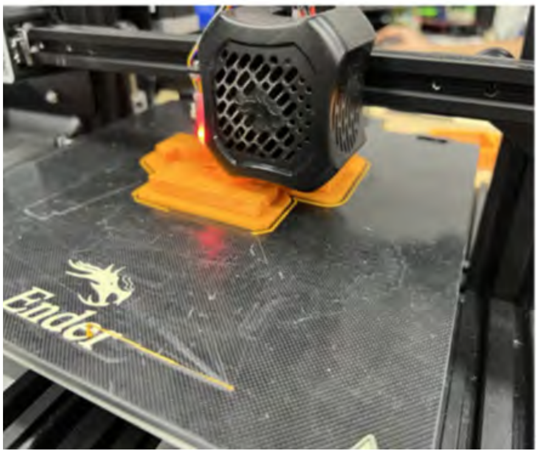


Fig. 9 3D Printing Prototype of Camera Mount

During prototyping, we used **SolidWorks** to create **3D-printed prototypes**, a cost-effective approach for our team. We tested these prototypes through computer simulation modeling, utilizing SolidWorks' fluid dynamic functions to deeply analyze the physical properties of our designs. Adjustments were made based on simulation results to enhance reliability.

Mechcanical

Design Evolution

Enhancing *Fronteer's* performance and functionality has remained a primary focus for our team. The new design accentuates flexible aiming and gripper control, integrating a **2-DOF gripper** with an improved gripping mechanism. In comparison to last year's iteration, the updated gripper, equipped with an elevator, facilitates easier catching and positioning of laying props. Additionally, we've refined the pulling pin catcher and enhanced the performance of the power connector.

Beyond the gripper mechanism, we've modularized the frame's material and design. **Carbon fiber** has been employed for the side plates to reduce weight and costs, contrasting with last year's use of **full 6061 aluminum alloy plates.** The revised frame also streamlines the installation and removal of the electronic tube, thereby **enhancing the overall design and maintenance experience.**

Frame & Structure

To address MATE's various challenges, we reinforced the frame's bottom with a custom-made **6061 aluminum alloy plate** for enhanced strength. We added a **nylon brace**, created using **Stereolithography** (**SLA**) **3D printing**, and carbon fiber plates on both sides to reduce weight. The shape of the SLA 3D-printed support perfectly matches the electronic tubes, effectively preventing damage.

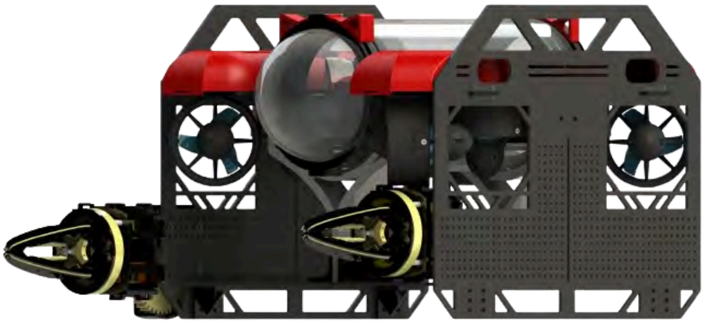


Fig. 10 45-degree side view of *Fronteer*

For tasks involving pulling props, we selected **6061 aluminum alloy and carbon fiber** due to their ability to hold additional components without screw nuts, reducing assembly time by eliminating unnecessary parts. Additionally, the frame features **uniformly spaced threaded holes and handle grips on the top**, making it easy for poolside operators to transport and lift the ROV. Other notable features include **ample mounting space** for different manipulators for various tasks, **improved cable management**, and **large frame openings** to allow water flow, enhancing movement. These design enhancements have improved *Fronteer's* performance, functionality, and overall efficiency.

Buoyancy

Since *Fronteer* has adopted an electronic tube design to store all electronics, the large volume of air from the tube provides positive buoyancy. Hence flexible buoyancy adjustment is necessary due to the vehicle's multiple add-on components. Polyurethane foam and lead weights can adjust buoyancy positively or negatively. PU foam was chosen for its low water absorption rate, high resistance to compression, and ease of shape adjustment for maintenance and fine-tuning. At the same time, lead weight has a higher density and takes up less space, allowing for a sleeker vehicle design. All this material will be grouped on the top part of the frame to make the center of buoyancy become more focused to increase the stability of the ROV.

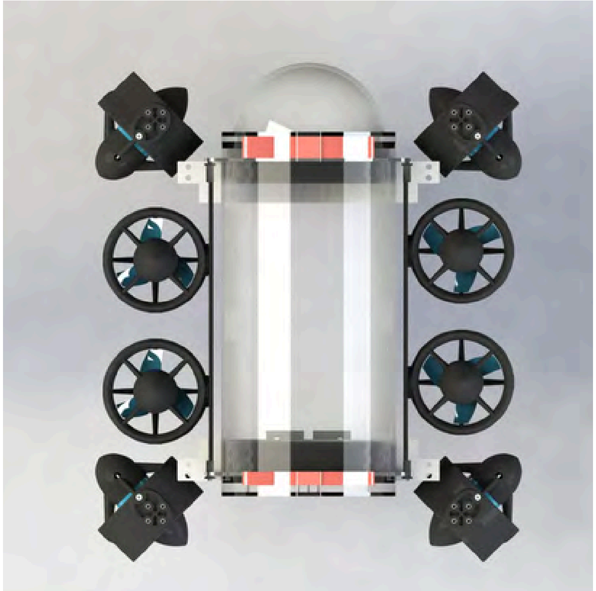


Fig. 11 Thruster Configuration

Propulsion

The propulsion system comprises **eight Blue Robotics T200** arranged in a vector configuration to achieve **6-DoF**. Four T200 motors control Sway, Surge, and Yaw, while the others control Roll, Pitch, and Heave. With the autopilot system, the vehicle could have complete control over its pose.

Fig. 12 T200 Thruster

Electronic Tube

The electronic housing is sealed inside the acrylic tube using CNC aluminum alloy flanges with **double O-rings, double aluminum alloy plates, acrylic plates, and spherical caps** at both ends. O-rings waterproof the tube. The electronic housing rack is mounted using four standardized aluminum studs for strength and threaded design. Two aluminum end plates direct the stud head to the corresponding threaded hole of the flange. The rack features two levels of slots: one for the power module and the other for the placement of motherboards on a carbon fiber plate.

Fig. 13 Exploded View of Container

System Architecture

The electronic system comprises four major components: the **voltage converter**, **motherboard**, **slotcard system**, and **single-board computer**. The 48V DC from the tether first passes through a 16.4V voltage converter. Then, supplies to the motherboard. The **slot card system** allows engineers to **customize the ROV's capabilities** for various underwater situations and operations by designing different slot cards (or daughter boards) that utilize a centralized signal bus.

This design, inspired by modern PC motherboard architecture, has enabled us to use **the same motherboard since 2018, showcasing its mature architecture compared to other systems lacking swappable PCBs.** A special power slot card is always installed to provide various voltages to the power bus on the motherboard. Finally, the pilot can issue commands to the single-board computer (SBC) via **powerline communication through the tether**, and **the SBC communicates with the desired daughterboards via the CAN Bus** integrated into the signal bus to control all manipulators on board.

Design Evolution

New components and daughter boards have been introduced this year to operate the innovative 2 DoF rotary gripper system, allowing the gripper to **adjust its gripping force** using current sensing techniques. Additionally, the CAN protocol has been introduced to centralize all communication between slot cards, offering more **flexibility** as message IDs are defined on the software side, enabling the **dynamic addition of nodes**. Minor modifications, such as updating components with newer technologies and redesigning the SBC voltage regulator, have been implemented to **improve the overall electrical stability, reduce the volume, and lower the cost of the ROV**.

Power

The ROV's power system uses four **telecommunication-grade DC-DC buck converters**. Each board has two converters connected in series, with the boards connected in parallel. The voltage steps down from 48V to 16.4V, with a maximum output of **90A and 1512W**. This new system offers improved stability and a lower failure rate compared to the previous version.

Tether

A **neutral-buoyancy tether** is used to minimize the impact of disrupting the ROV's movement due to the pull-down force from a standard tether's weight. It consists of eight signals and a pair of thicker power lines. **TPE sponges** covered by a corrosion-resistant PUR outer layer are used to **provide buoyancy and counteract the weight** of the copper lines. Additionally, special **Kevlar structures** and aluminum foil provide **tensile strength** and **signal shielding.**

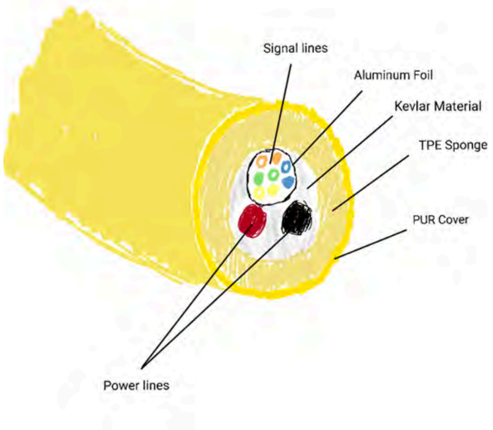


Fig. 14 Cross section of the tether

Communication

To achieve communication between *Fronteer* and control station, an **Optical Fiber Transceiver** and a **Powerline Communication Unit** are used in parallel for redundancy. The former uses one of the two optical fiber core in the tether to transmit video and ethernet signal while the latter is a backup system which uses the 48V powerline in the tether to transmit ethernet signal.

Backplane

To enhance subsystem management, *Fronteer* features a backplane divided into three parts: **Main Board, Rear I/O**, and **Power Board**, along with an **SBC with autopilot**. The backplane utilizes defensively designed plugs and daughter board slots to prevent connection errors. A high-efficiency heat dissipation design prevents overheating. The new backplane version reduces PCB length while maintaining functionality, freeing space in the housing for upgrades like a more powerful SBC or a ZED camera. With five daughter board slots, the modular design allows independent sub-systems to share power and signal buses, ensuring reliability and easy upgrades.

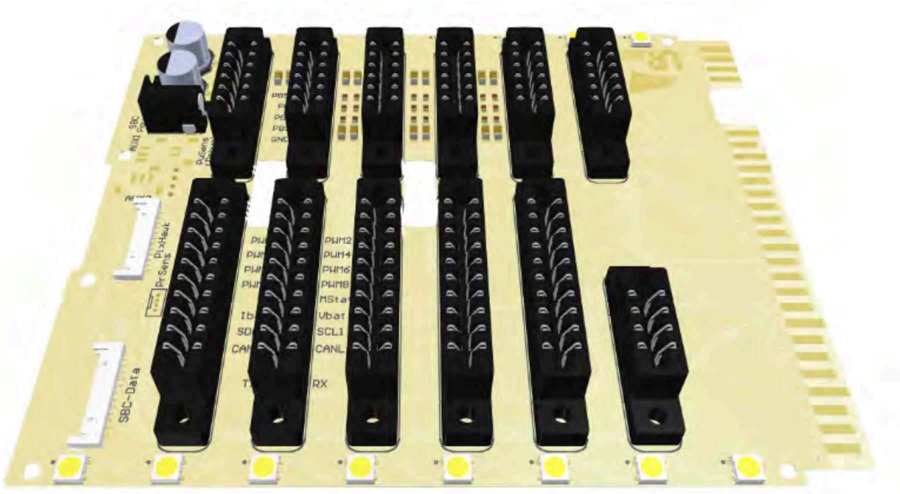


Fig. 15 Rendered *Fronteer's* Backplane

Manipulator Board v5

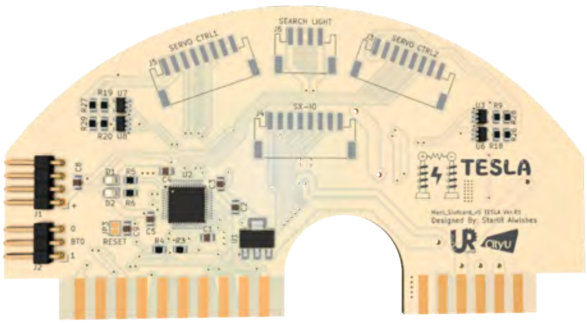


Fig.16 Rendered manipulator baord v5

The manipulator board receives commands from the SBC via the CAN Bus and then converts them to its corresponding electrical signal for controlling the servos of manipulators. **Current sensing circuitry** is implemented, allowing **adjustment of the torque output of the servos**, and it has been improved for more **generic usage**, including having **multiple ADC, GPIO, and Load Switches** on board to **prepare for the future**.

Debug Board

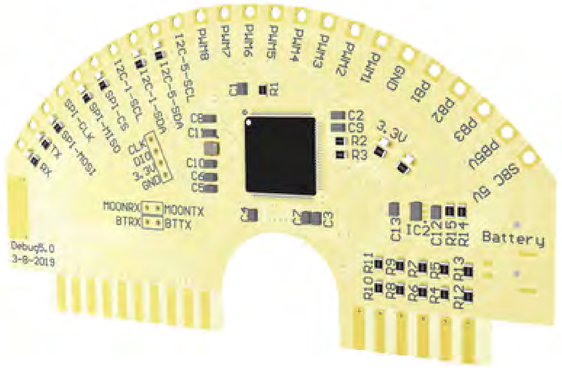


Fig. 17 Rendered debug board

The debug daughter board is used to **speed up hardware diagnosis** of the backplane by providing visual indications and test holes around the edge of the card. These holes are connected to the power, signal, and thruster control buses. Engineers can directly connect a logic analyzer or oscilloscope to the test holes in case of any error. Alternatively, measurements from various buses can be viewed from other devices via **Bluetooth**. Such design allows engineers to understand the status of the vehicle without the need to open the electronic tube.

Camera and Peripheral Daughter Board

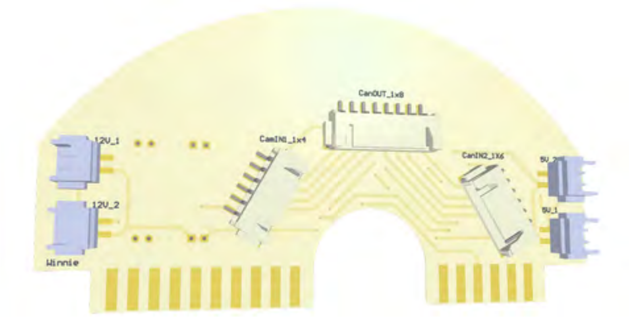


Fig. 18 Rendered Camera and Peripheral Daughter Boards

The camera and peripheral daughter board routes **video outputs to distinct signal channels**, providing well-ordered video feeds for the pilot. To fully utilize the camera, a servo motor controls the camera's rotation, and an onboard step-down voltage regulator **converts 12V to 5V** for the servo motor.

SBC Power System

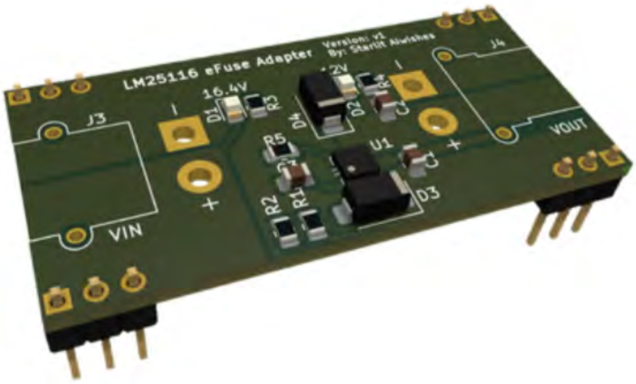
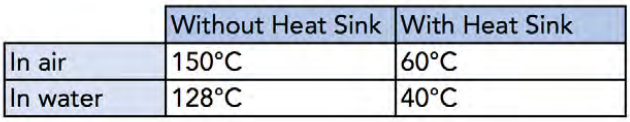


Fig. 23 Rendered SBC Protection Module

An additional power converter module is used to power the **Jetson Orin Nano** system in the ROV. This new module will convert the system power into **12V 30W output** to a DC jack for the Jetson Orin Nano. Besides, this new module utilizes the **PCB stacking** technique to optimize space usage. Moreover, an **eFuse adapter PCB** is designed on top of the **LM25116 power converter**. This adapter can monitor **short circuits**, **over or under-voltage**, and **over-current** in order to **break the circuit** or apply corresponding champ protection immediately with the ability to **auto-recover** after the incident is resolved.

Electronic Speed Controller (ESC)

Fig. 19 ESC with heat sink



	Without Heat Sink	With Heat Sink
In air	150°C	60°C
In water	128°C	40°C

Table 2: Comparison of ESC temperature

To control and regulate the thruster speed, *Fronteer* uses eight 20A ESCs. Previously, traditional sealing methods caused ESC temperatures to reach 150°C, unsuitable for prolonged operation. To prevent overheating and reduce accident risks, our engineer integrated a heatsink with heat-conductive epoxy into the ESCs. These ESCs are **positioned outside** the electronic tube, allowing for passive water cooling. This approach significantly lowers ESC temperatures to **around 60°C in air** and **not higher than 40°C in water**, ensuring safer and more efficient operation.

Vision

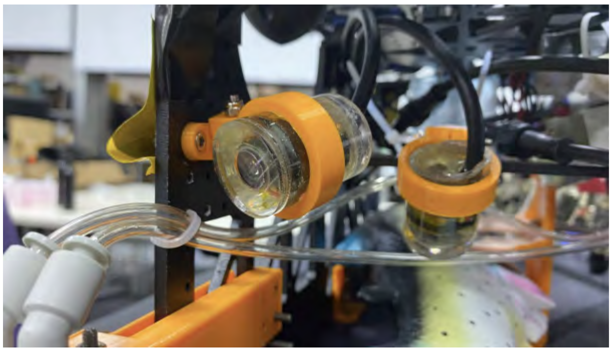


Fig. 20 Analog cameras positioned on frame

Seven auxiliary cameras were installed onto the *Fronteer*, including **one digital camera, one stereo camera, and six analog cameras** to provide different view angles for the pilot to complete underwater tasks. Both digital and stereo cameras can change the viewing angle, allowing the pilot to search for objects at different heights. The digital camera is inside the main electronics compartment, whereas the other cameras are outside. In contrast, the 6 four analog cameras are task-specific cameras that aim to focus on the manipulators, and the stereo camera is mainly for doing computer vision tasks.

Control Station

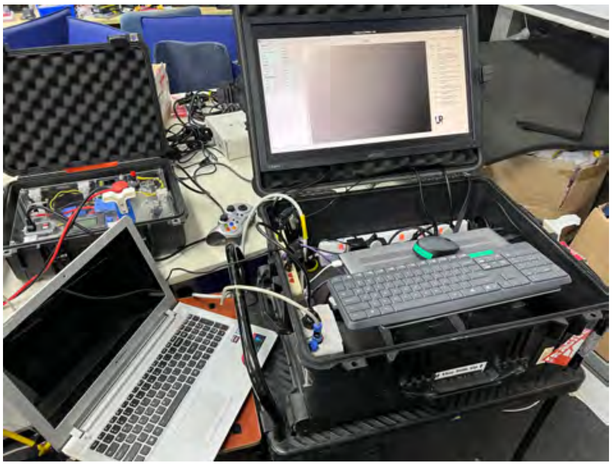


Fig. 21 Ground station of *Fronteer*

Throughout the continuous development, the control station became a central controlling hub that integrated the central computer, network module, powerline communication module, and controlling device. The control station utilizes a modified pelican container to house all the components, allowing crew members to quickly mobile the entire control station and the vehicle. A laptop with a dedicated graphic processing unit is installed to provide a lightweight and powerful setup that handles different computation devices.

Design Evolution

This year, we undertook a complete redesign of our software system. We focused on enhancing the **user interface and experience** (**UI**/**UX**) for the pilot team while prioritizing e**ase of development, reusability, and robustness** for the backend

Software System Architecture

Our backend software relies on **ROS2** and **Docker**. We containerize software components into nodes using Docker, ensuring efficient and accurate replication of our system in case of onboard computer failure. Moreover, developers can now work locally with a consistent environment without relying on the onboard computer. ROS2's decentralized node discovery system operates automatically without requiring a master node, unlike ROS1. This approach enables seamless communication between nodes as long as they are running and connected to the same network, significantly enhancing the robustness of our system.

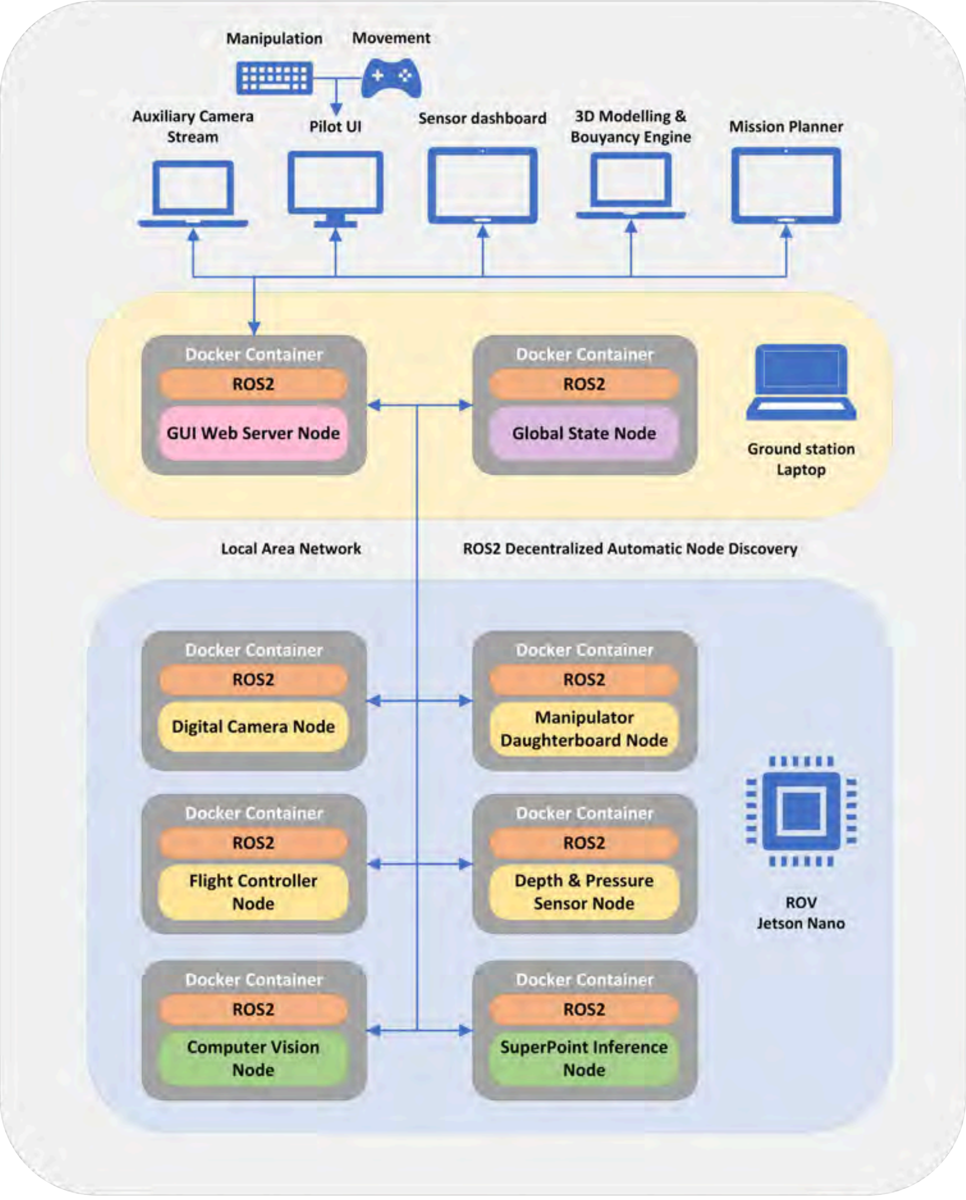


Fig. 24 Software system architecture

Graphical User Interface

Our Graphical User Interface (GUI) enables pilots to monitor and control the ROV from the ground. Developed in **ReactJS**, it interfaces with our backend **ROS2 web socket**. Unlike our previous RQt desktop GUI, the new GUI is accessible on any device with a browser, enhancing equipment **portability**. Pilots can view sensor values, mission timelines, auxiliary camera feeds, and buoyancy engine controls on tablets and laptops without additional dedicated monitors. The pilot UI supports joystick and keyboard input for ROV control.

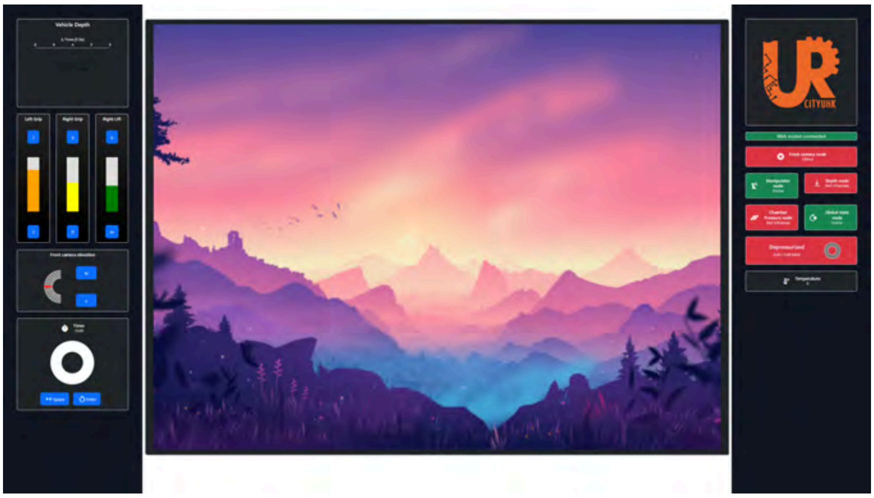


Fig. 25 Control Station GUI

Simulation

Our simulator software provides a sandbox for simulating competition environments. Developed using **Unity** with **CAD** and **Blender** support, it enables the creation of high-quality underwater scenes. Coupled with our physics engine incorporating water physics, resistance, buoyancy noise, and waves, the simulator serves as a training ground for pilots and algorithms.

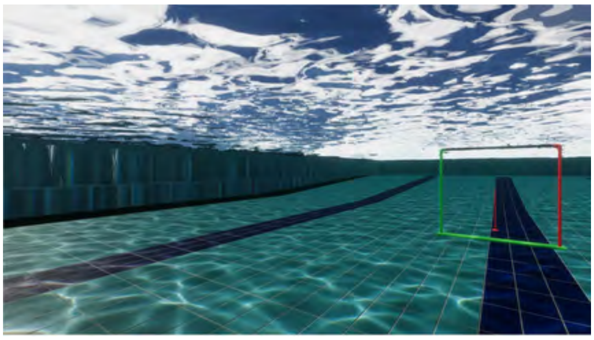


Fig. 26 Underwater simulation graphic

Computer Vision

We have developed a **photogrammetry algorithm pipeline** for autonomously determining the dimensions of the coral restoration area. Initially, the stereo camera stream undergoes preprocessing and distortion correction using calibration parameters. Next, feature points are extracted from the stereo images using the **SuperPoint** machine learning model, which surpasses conventional algorithms like ORB in extracting pool features.

The feature points from both images are then matched to calculate their distance from the cameras. Subsequently, the points undergo post-processing to retain only those relevant to the **coral restoration area**. This is achieved by estimating the normal vector of the pool floor and disregarding points close to the floor. The remaining point cloud is transformed from the camera coordinate system to the ground coordinate system. By creating a bounding box of the point cloud, we can accurately determine the width and height of the model.

Fig. 27 Retrived image from camera

Fig. 28 Constructed point cloud of item

Mission-specific Tools

General-purpose Gripper

This gripper is equipped with a **rotary mechanism** utilizing bearings, servo motors, and gears to enhance flexibility. Its four jaws are driven by a servo with a **ball screw**, allowing for linear movement. Each jaw consists of **two carbon fiber plates** and a **TPU 3D-printed component as the middle layer**. The carbon fiber provides strength, while the TPU components offer flexibility and adaptability, enabling the gripper to handle objects of various shapes, deploy, return, install, and pull props effectively.

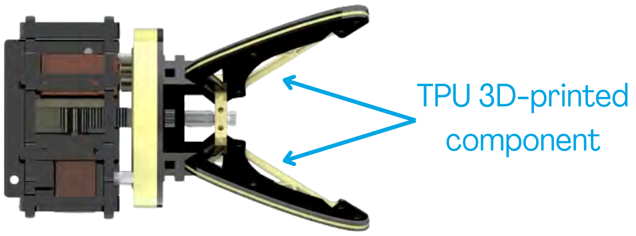


Fig. 29 Rendered ide view of the gripper

Fig. 30 Rotation component

Fig. 31 Rendered image of the gripper

Elevating Gripper

Our company designed the new elevating gripper by repurposing a **270-degree servo** from last year's components. The servo transfers its rotary motion to a gearbox with a reduction ratio of **1:3**. This gearbox connects to a unique parallelogram-shaped mechanism, facilitating the gripper's upward and downward movement while maintaining a horizontal orientation. Our calculations indicate that a standard servo with a **torque rating of 45 kg/cm** can lift an object weighing up to **10 kg**. We built the connecting rod entirely from standard parts, enhancing operational stability and cost-effectiveness. Additionally, we included a protective case to mitigate potential injuries.

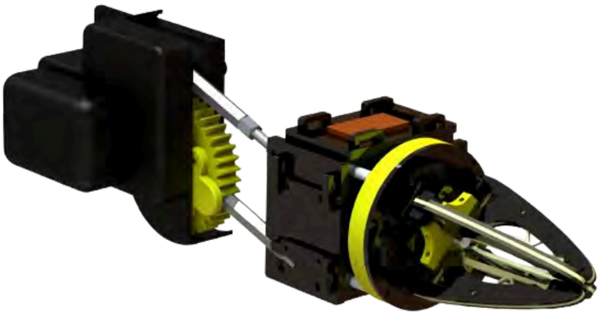


Fig. 32 Rendered elevator arm

Fig. 33 Rendered elevator arm (side view)

Recovery Line

The new design replaces the traditional design of using a rope to connect the carabiner and the water pipe. Instead, it uses 3D-printed components to inlay the water pipe with a **diameter of 2.5cm**. It uses an iron wire with high resilience as a spring so that the clip can automatically rebound and close the gate itself. This design ensures that the tool will not fail the task due to a loose connection position. At the same time, a buckle is designed with a groove to facilitate alignment by the pilot.

Fig. 34 Rendered downward gripper

Sediment Collector

The **dual-shovel design** of the sediment sample collector group is engineered to grasp objects effectively. The collector assembly features a shovel inspired by **a bulldozer design**, which prevents objects from spilling outward. The collectors are connected on both sides of the gripper claw by an axis rod, enabling synchronized movement. Additionally, the collector allows for **quick installation**. The sediment sample collector primarily focuses on picking up rocks during the task.

Fig. 35 Rendered sediment collector

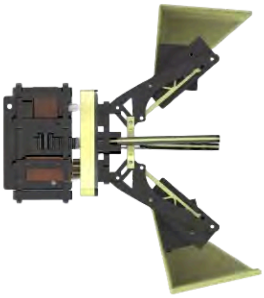


Fig. 36 Rendered sediment collector (top view)

Camera Mount

We developed an innovative solution for tasks requiring precision in-camera mounting, offering a range of functionalities. Our camera mount system consists of three components: **a top camera mount, a middle pit angle mount, and a bottom yaw angle mount**. The dual-angle mount features a hexagonal pit for stable angle positioning. Adjustability is key, with screws facilitating easy modifications to the camera angle, providing a **full 180-degree view**. The angle can be **hand-adjusted**, and the hexagonal pit maintains the chosen angle securely. This camera mount securely holds the camera and provides **real-time zoom-in capabilities on the gripper's conditions.**

Fig. 37 Rendered camera mount

Mission Planner

The mission planner tool aids pilots in time management by presenting task content as timelines. Pilots can create, modify, and store competition strategies using a tablet. Timelines synchronize with the pilot timer, and speakers announce remaining time.

Fig. 38 The mission planner GUI

3D Modeling

The 3D model of the coral restoration area is created using **OpenSCAD**. The OpenSCAD script is pre-loaded into our **ReactJS GUI,** which uses OpenJSCAD to render the model. Co-pilots can then use the GUI to scale the model based on the dimensions received from the judge.

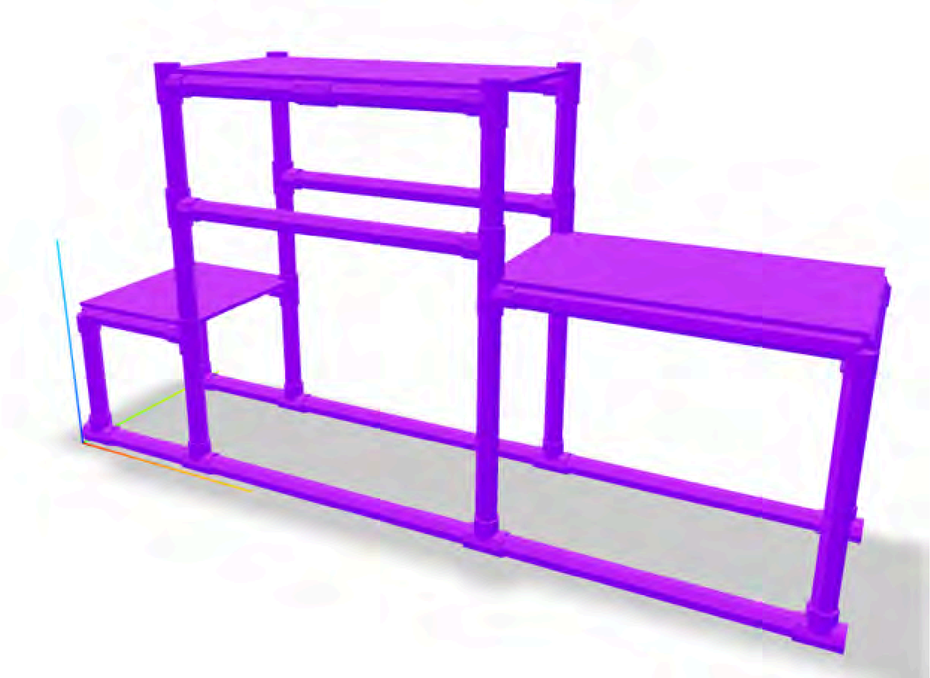


Fig. 39 Rendered 3D Model

Buoyancy Engine

The buoyancy engine is designed to autonomously perform vertical profiles by adjusting buoyancy. This is achieved by regulating water in a syringe to alter the engine's density. A linear actuator, housed in a waterproof enclosure, is connected to the plunger of a 300 mL syringe outside the enclosure. The enclosure is a tube with a 100 mm inner diameter, 110 mm outer diameter, and 400 mm height. The linear actuator converts the electric motor's rotary motion into linear motion, activated by a signal from the ground station.

The linear actuator moves the stroke rod, pulling the syringe plunger and driving water into the syringe to increase the engine's density. A pressure sensor collects data during this process. The engine monitors pressure changes to determine if it is sinking; if not, the actuator continues to operate. Once the engine reaches the bottom, the mechanism pushes the syringe, withdrawing water to reduce weight and enable ascent.

Electronic components are positioned at the upper part of the enclosure. A printed circuit board controls the linear actuator and collects data from the pressure sensor. The GC433-TC018 LoRa module, chosen over the HC-05 Bluetooth module, features a 433MHz antenna to enhance signal strength. While the GC433-TC018 LoRa module has a lower transmission rate than Bluetooth, its higher receiver sensitivity ensures a wider transmission range.

Fig. 40 Rendered buoyancy engine (side view)

Fig. 41 Rendered buoyancy engine (front view)

SAFETY

Safety Philosophy

Safety is paramount at CityUUR. Our team places the utmost importance on the safety and well-being of our team members in all tasks we undertake. *Fronteer*, our meticulously designed vehicle, meets stringent safety requirements and standards, thus mitigating the risk of injuries to our personnel during both operation and vehicle logistics.

Establishing a safe working environment for our team members is of paramount importance. Our company has developed various safety protocols tailored to different scenarios, whether it involves constructing or operating an ROV.

Safety Features of the ROV

Our team of mechanical engineers has implemented numerous safety features on *Fronteer* to ensure the safety of both crew members and the environment during operation:

- All moving parts and hazardous components are **labeled with eye-catching labels** that are noticeable to users.
- **No sharp edges** are exposed during the main frame construction or manufacturing of other hardware components.
- All manipulators attached to the grippers are protected with **shrouds**, preventing users from rolling injuries caused by gear movements.
- The **propellers** are protected with shrouds, which protect users from cutting injuries caused by propeller blades.
- A **kill box** containing a fuse and a kill switch can shut off the system immediately in case of an emergency or abnormal operation.

In addition to hardware safety measures, our software engineers have developed several systems to monitor *Fronteer's* status and preempt any unstable situations:

1. Fail-safe system: A system that **recalls the *Fronteer* to surface** once the connection is closed. The measure could prevent the loss of vehicles during its expedition. A signal would be sent to the onboard LED strip, which indicates the vehicle's status in patterns and colors, for instance, **'Power On,' 'Bug Detected,' 'Performing Mission,' or even 'High Current**.' The pilot could decide according to the status shown.
2. Management Unit: A unit with a power sensing system and overcurrent protection is used to trace the current performance of the system and provide protection over overcurrent, short-circuits, overvoltage, and transient voltage. In case of an emergency, ECPO can be activated in **two modes** depending on the situation, to cut off power only to the thruster or the whole vehicle.

Fig. 42 Backplane with fail-safe system and LED display

Operation Safety Protocol

Our operators are required to complete a safety operation checklist (attached in Appendix C) before, during, and after any operations. This standardized procedure enables operators to assess the functionality and status of the ROV, thereby safeguarding them against potential risks or injuries.

Lab Safety Protocol

CityUUR conducts mandatory annual lab training sessions for new members to familiarize them with workplace safety and lab practices. Each training session spans two hours, during which senior engineers demonstrate safety measures, including the proper use of personal protective equipment (PPE), machinery, and emergency procedures. Peer evaluations are conducted during these sessions to foster a culture of safety awareness among our members. Through such initiatives, every member comprehensively understands workplace safety measures, thereby prioritizing 'safety' as the cornerstone of our company's values.

To ensure a safe working environment, members are required to review and utilize **Job Safety Analysis** (**JSA**) **forms and PPE** before engaging in any activities involving heavy machinery, thus minimizing potential risks and threats to our team members.

Fig. 43 Peer Training System when performing heavy machinery

ACCOUNTING

Project Budget and Expense

Fronteer's budget is set at the beginning of the year and estimated according to the previous project, covering every expense involved, including the cost of ROV construction and maintenance, the MATE Competition fee, and the company's daily operation expenses. In this year's planning, major expenses come from pool rental and new ROV components.

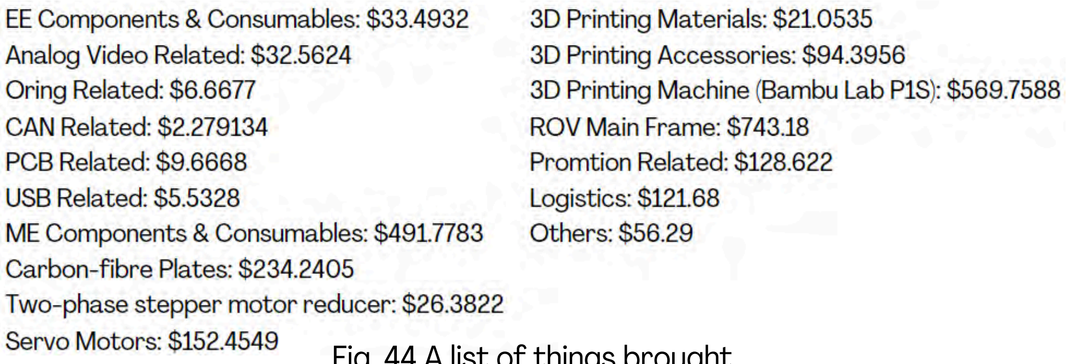
Developing under a limited amount of resources available, our company executes a tide and essential financial planning and monitoring, and each department has a strict budget to follow. All the purchases will have to be reviewed and approved by the department head, and all the receipts will be recorded in the monthly expenditure list for tracking purposes.

Reused & Brought Items

Reused

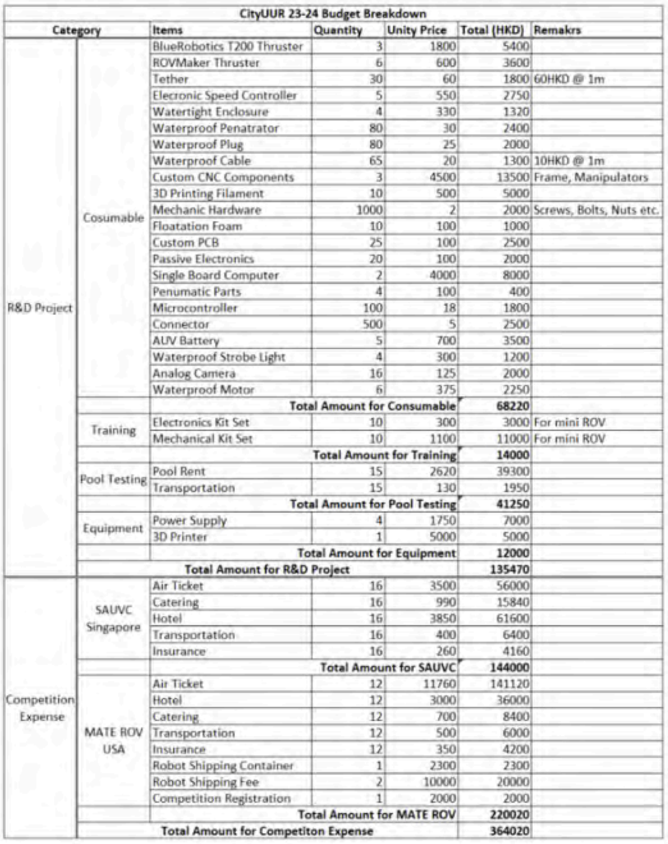
Control station
Jetson Orin Nano
Pxhawk
power slot cards
ESC
BlueRobotics T200 thrusters
Thruster guards
Camera mount
Electronic tube

Brought



EE Components & Consumables: $33.4932
Analog Video Related: $32.5624
Oring Related: $6.6677
CAN Related: $2.279134
PCB Related: $9.6668
USB Related: $5.5328
ME Components & Consumables: $491.7783
Carbon-fibre Plates: $234.2405
Two-phase stepper motor reducer: $26.3822
Servo Motors: $152.4549
3D Printing Materials: $21.0535
3D Printing Accessories: $94.3956
3D Printing Machine (Bambu Lab P1S): $569.7588
ROV Main Frame: $743.18
Promtion Related: $128.622
Logistics: $121.68
Others: $56.29

Fig. 44 A list of things brought



CityUUR 23-24 Budget Breakdown

Category		Items	Quantity	Unity Price	Total (HKD)	Remakrs
R&D Project	Cosumable	BlueRobotics T200 Thruster	3	1800	5400	
		ROVMaker Thruster	6	600	3600	
		Tether	30	60	1800	60HKD @ 1m
		Elecronic Speed Controller	5	550	2750	
		Watertight Enclosure	4	330	1320	
		Waterproof Penatrator	80	30	2400	
		Waterproof Plug	80	25	2000	
		Waterproof Cable	65	20	1300	10HKD @ 1m
		Custom CNC Components	3	4500	13500	Frame, Manipulators
		3D Printing Filament	10	500	5000	
		Mechanic Hardware	1000	2	2000	Screws, Bolts, Nuts etc.
		Floatation Foam	10	100	1000	
		Custom PCB	25	100	2500	
		Passive Electronics	20	100	2000	
		Single Board Computer	2	4000	8000	
		Penumatic Parts	4	100	400	
		Microcontroller	100	18	1800	
		Connector	500	5	2500	
		AUV Battery	5	700	3500	
		Waterproof Strobe Light	4	300	1200	
		Analog Camera	16	125	2000	
		Waterproof Motor	6	375	2250	
		Total Amount for Consumable			**68220**	
	Training	Electronics Kit Set	10	300	3000	For mini ROV
		Mechanical Kit Set	10	1100	11000	For mini ROV
		Total Amount for Training			**14000**	
	Pool Testing	Pool Rent	15	2620	39300	
		Transportation	15	130	1950	
		Total Amount for Pool Testing			**41250**	
	Equipment	Power Supply	4	1750	7000	
		3D Printer	1	5000	5000	
		Total Amount for Equipment			**12000**	
	Total Amount for R&D Project				**135470**	
Competition Expense	SAUVC Singapore	Air Ticket	16	3500	56000	
		Catering	16	990	15840	
		Hotel	16	3850	61600	
		Transportation	16	400	6400	
		Insurance	16	260	4160	
		Total Amount for SAUVC			**144000**	
	MATE ROV USA	Air Ticket	12	11760	141120	
		Hotel	12	3000	36000	
		Catering	12	700	8400	
		Transportation	12	500	6000	
		Insurance	12	350	4200	
		Robot Shipping Container	1	2300	2300	
		Robot Shipping Fee	2	10000	20000	
		Competition Registration	1	2000	2000	
		Total Amount for MATE ROV			**220020**	
	Total Amount for Competiton Expense				**364020**	

Table 3: Project costing and budget

CONCLUSION

Testing & Troubleshooting

Testing is a critical phase that verifies our ideas and designs through practical application. Objective analysis and prototype comparison are essential for evaluation and decision-making.

We built several prototypes based on different designs and ideas, undergoing various tests. Initially, we tested each component independently to assess their performance. This individual testing allows us to better understand each component's functionality and stability, which is crucial in system design. We also utilized simulation tools such as the Gazebo simulator and SolidWorks. SolidWorks simulates and verifies hardware functionality, while the Gazebo simulator tests the vehicle's software. Using simulation tools saves time and money compared to constructing physical models, providing reliable results with minimal effort.

However, some errors in simulation, such as round-off and truncation errors, are unavoidable. Therefore, pool tests are necessary to evaluate the performance and practicality of our vehicle's design. Parameters including stability, efficiency, buoyancy, manipulation, and overall performance are assessed during the pool tests.

A systematic and logical approach is employed to address problems using a trial-and-error method while adhering to safety requirements. By identifying, eliminating, testing, validating, and modifying, we troubleshoot various issues.

Due to various undesirable factors, the vehicle may not meet our expectations during testing. Therefore, we simulated scenarios multiple times to identify these factors. We then referred to the original concepts and fundamental theories to eliminate the undesirable factors. Subsequent tests were conducted to validate our hypotheses, and finally, we modified the design by altering the structure.

Fig. 45 Approach of troubleshooting

Challenges

Technical

Our modular backplane integrated every sub-system. In such a high-density environment, noise reduction and thermal performance were the year's biggest challenges. One solution to reduce noise is to separate the power and signal on the PCB design. As such, our electronic engineers have done a series of PCB iterations for different hardware isolation methods to lower the noise level, which our engineer has successfully reduced to an acceptable level.

However, our engineer found that heat from the power system and external sources caused certain 3D-printed parts in the electronic housing to melt when the vehicle was left in the sun for extended periods. We have tried different cooling methods to prevent overheating, but the optimal solution is still pending. To ensure system stability under high temperatures, we have subjected our PCBs to an oven test to confirm they can remain functional at 100°C for 30 minutes.

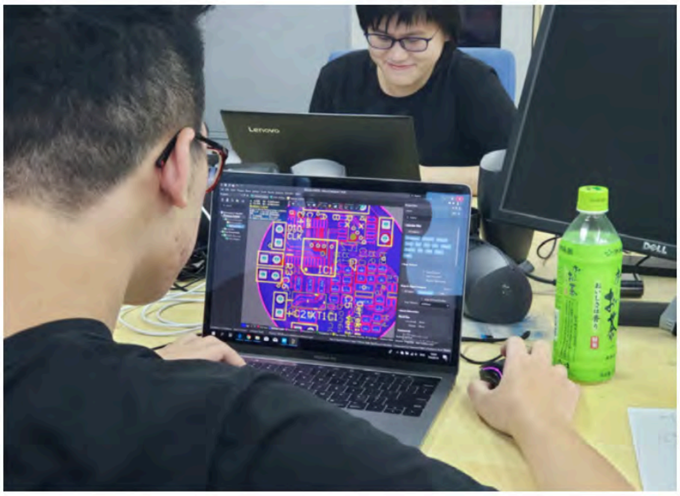


Fig. 46 Electronic Engineer drawing PCB

Fig. 47 Iteration of PCB

Non-technical

CityUUR is an organization consisting of approximately 31 members. Team management, communication, and division of labor are ongoing challenges. Information flow is maintained using various platforms, allowing members to access the most up-to-date files and work on them simultaneously for better collaboration. Freedcamp is used to set schedules for members, ensure project progress is on track, and allocate workload efficiently.

Resource management, including financial resources, is another challenge. With a limited budget, the purchase of some components may be delayed due to cash flow constraints, slowing project progress. Effective financial planning is one solution, with purchases prioritized based on current cash flow and product availability. Fundraising is another approach, with the company seeking sponsorships and donations by organizing activities such as workshops.

Lessons Learned & Skills Gained

Technical Lesson Learned

As previously mentioned, we used a modular electronic system this year. All peripheral systems were integrated into the daughter board, while the main system was incorporated into the backplane. This system was developed based on a master template, which guided the development of other circuits. Our engineers found that the master template greatly streamlined workflow and simplified processes. It allowed engineers who were less familiar with the electronic system to work on specific subsystems. Extensive simulations were conducted throughout the mechanical design process for the manipulator and frames, validating the design before manufacture.

Interpersonal Lesson Learned

Each year, new engineers are recruited into the company as the Junior team. Bridging the gap between junior and senior members can be challenging due to unfamiliarity with the new environment and the diverse cultures and backgrounds of the team. Therefore, boot camps and ice-breaking sessions are held to increase interaction between junior and senior engineers, fostering a sense of belonging and bridging the gap to create a vibrant team spirit.

Skills Gained

This year marked a significant milestone as we transitioned from a combination of pneumatic and electrical systems to a fully electrical setup to control manipulators. Our engineers undertook meticulous measures to ensure the stability of the electronic system. They conducted thorough testing and validation of the new electrical components, implemented robust fault detection and protection mechanisms, and established redundant systems where necessary. Their unwavering dedication and attention to detail have been instrumental in ensuring the reliability and performance of the electronic system in *Fronteer*.

Future Development

Design

Developing components in-house is a key goal for our future projects. For instance, we aim to implement Field Oriented Control (FOC) ESC, which can provide more accurate and efficient control over thrusters, particularly at low RPM. This allows for micro-maneuvering and better precision.

In-house development is also planned for our auto-pilot system. Our current commercial product may not be suitable for future developments, prompting the need for a design that better suits our requirements.
Lastly, we are considering developing in-house optical fiber transceivers based on FPGA. The available product in the market is bulky and includes many unnecessary components. A custom solution would allow us to reduce the size and function to meet our needs.

Better Project Management Approach

To achieve better project management, get knowing each member's strengths and weaknesses- es will certainly improve the performance and productivity of the team in coming projects. From observation, there is an imbalance of workload between members. It is essential to pay more effort into familiarizing the team's pace. This can achieve better management in terms of task distribution and manpower mobilization, thus fostering effective collaboration.

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CityUHK Department of Electrical Engineering - Their R&D and travelling funding to the team
CityUHK Department of Computer Science- Their R&D and travelling funding to the team
CityUHK Department of Biomedical Engineering- Their R&D and travelling funding to the team
CityUHK School of Data Science - Their travelling funding to the team
CityUHK Department of Mechanical Engineering - Their R&D and travelling funding to the team
CityUHK Student Development Services - Their travelling funding to the team
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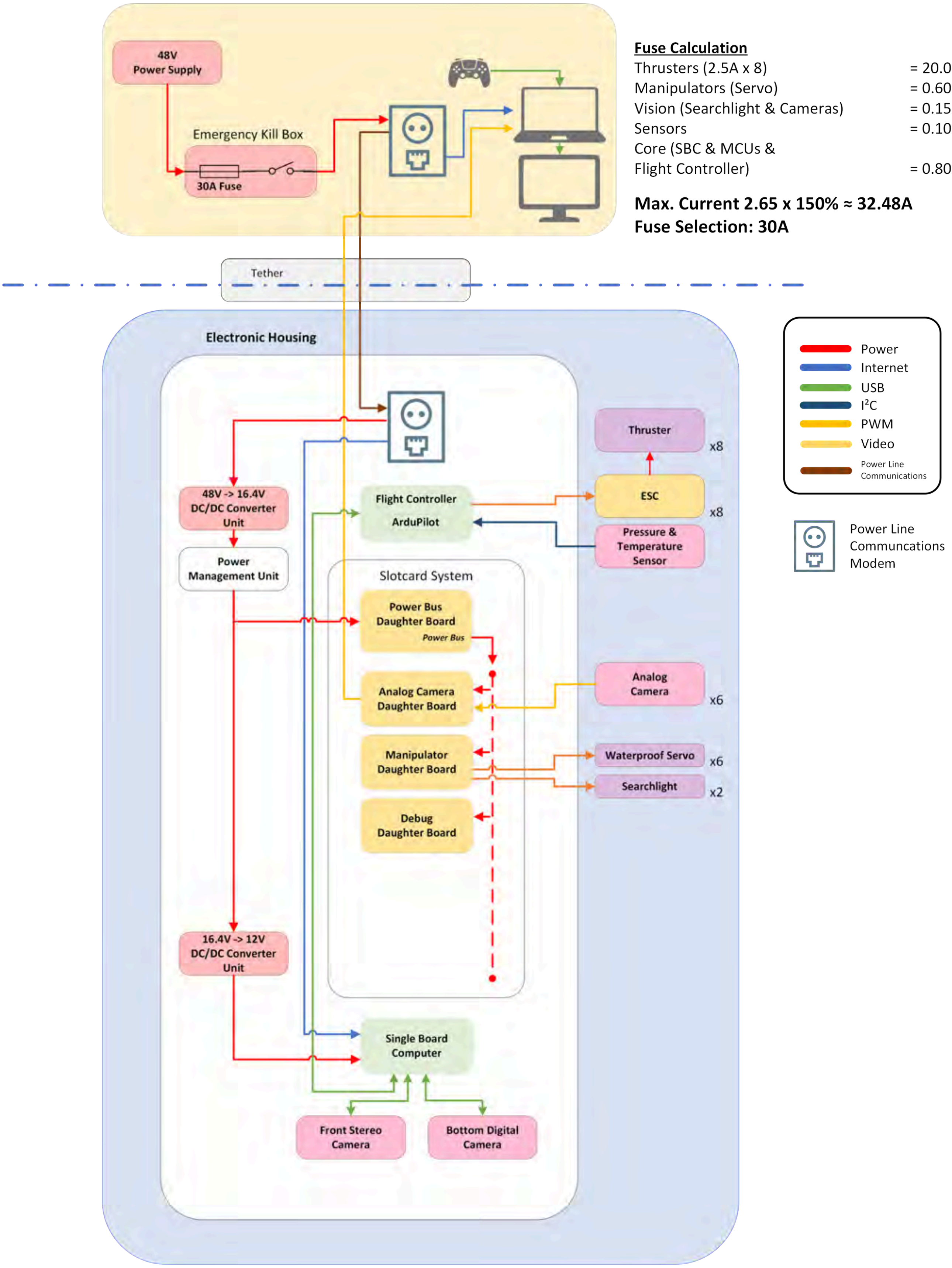
A. System Interconnection Diagram (SID) - Electrical

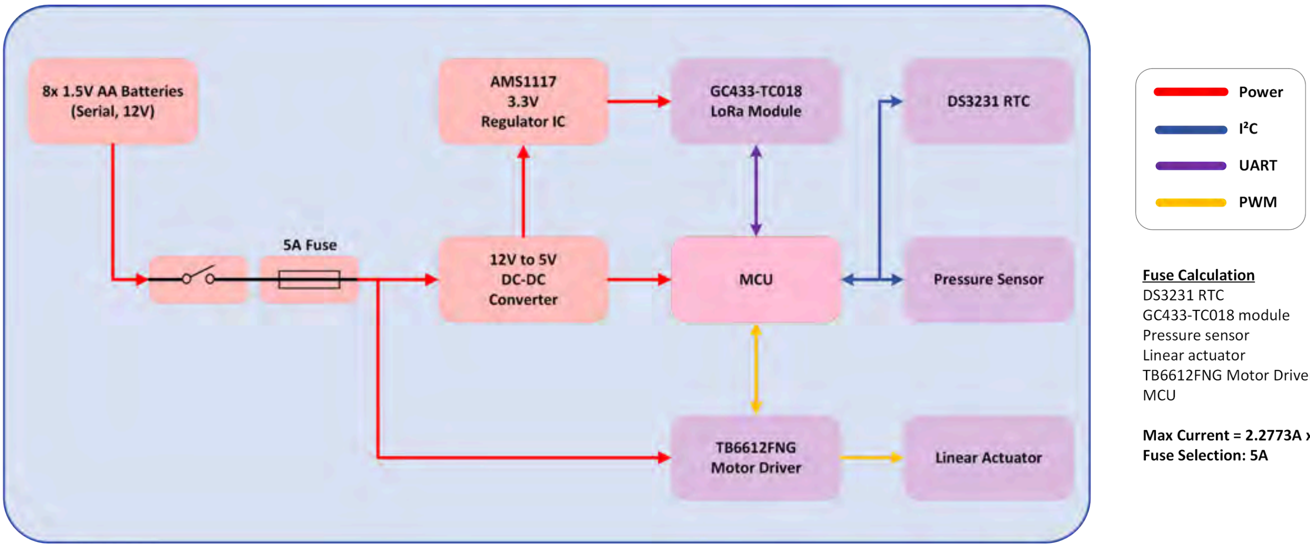


Fuse Calculation

Thrusters (2.5A x 8)	= 20.00A
Manipulators (Servo)	= 0.60A
Vision (Searchlight & Cameras)	= 0.15A
Sensors	= 0.10A
Core (SBC & MCUs & Flight Controller)	= 0.80A

Max. Current 2.65 x 150% ≈ 32.48A
Fuse Selection: 30A

B.System Interconnection Diagram (SID) - Buoyancy Engine and Ground Receiver



Fuse Calculation

DS3231 RTC = 0.0003A
GC433-TC018 module = 0.138A
Pressure sensor = 0.1A
Linear actuator = 0.5A
TB6612FNG Motor Driver= 1.0A
MCU = 0.539A

Max Current = 2.2773A x 120% ≈ 2.73A
Fuse Selection: 5A

C.Safety Operation Checklist

Operation Safety Checklist

Start-up Procedure

- ☐ Safety goggles are worn for every crew
- ☐ All crew members are not dangerously near to the ROV
- ☐ Ensured Main switches and circuit breaker on Surface Control Unit are off.
- ☐ Checked that tether is connected to and from ROV is secure and non-damage
- ☐ Double checked that bolts are secure in position
- ☐ Double checked that all jubilee clips are well tightened.
- ☐ Double checked that all wires are properly connected, without any unwanted exposure
- ☐ Double checked that all component's waterproofing status are nominal
- ☐ Ensured that the thrusters are not obstructed by any sort of obstacles, such as wire

Upon Supplying Power to the ROV

- ☐ Ensured that all member are away from the water
- ☐ Informed everybody on deck before power is on.
- ☐ Ensured that all members are attentive and prepared
- ☐ Power source is switched on and connected to Surface Control Unit.
- ☐ Verified that the voltmeter reading is 48 volts on the LCD
- ☐ Warned everybody on deck for thruster test
- ☐ Ensured that the GUI is started and codes are ready to run.
- ☐ Ensured that the thruster test is properly performed without abnormalities
- ☐ Ensured that no abnormalities (shoddy feed etc) are found on the display
- ☐ Tested accessories

Launch

- ☐ Hands are removed from the ROV control panel
- ☐ Called "Prepare to launch"
- ☐ Ensured all deck members are ready
- ☐ Called "Launch"
- ☐ Ensured ROV is completely submerged to water
- ☐ Wait for release

In Water

- ☐ Tether man is attentively placing the ROV in water.
- ☐ Checked for bubbles that could mean any leakage.
- ☐ Checked for all motors and servomotors functionality
- ☐ If a burned out smell is detected, reel ROV back to surface as soon as possible
- ☐ Everything is OK, begin mission

ROV Retrieval

- ☐ Called "Prepare for surfacing"
- ☐ Ensured that crew members are ready for retrieval of ROV
- ☐ Ensured the ROV is somewhere near to the crew
- ☐ Killed power after confirmation of retrieval
- ☐ Ensured no power leak, called out "safe to remove ROV"
- ☐ "ROV secured on deck" is called out after ROV is secured

Loss of Communication / Unresponsive

- ☐ Checked if all connections are secure
- ☐ Rebooted the communication system
- ☐ If failed: pull out and plug all wires again
- ☐ Troubleshoot succeed: mission continues as usual
- ☐ Troubleshoot failed: Kill power
- ☐ Retrieved ROV via tether