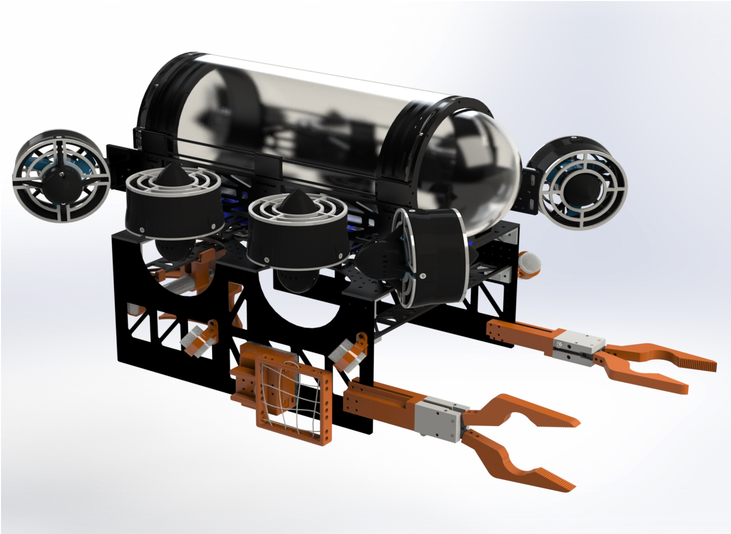
CITYUHK

cityu underwater robotics

FRONTEER ROV

2022 MATE ROV TECHnical REPORT



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abstract 1

Fig.1 CityU Underwater Robotics 2022

CityU Underwater Robotics ("CityUUR") consists of thirty multicultural students who are enthusiastic about underwater robotics. The company has developed a remotely operated underwater vehicle ("ROV") with an innovative design for supporting the work of sustainable development. It works to combat climate change and preseve the maritime history, and the most important to develop for the ocean future we want.

Fronteer is the culmination of previous experiences and countless experimentations - for this year's Fronteer, our team has made further refinements to our design, with previous performance-related issues coming into priority behind our consideration; from a mechanical and optical standpoint, widening our horizons was key; this was done by introducing a new camera mount with a rotational design. Major changes have also been implemented into the electronics of our ROV, in the form of a more compact motherboard and advanced daughterboard system to make room for further refinements and enhance flexibility and mobility, as well as a new voltage introduced for greater stability. Multiple simulation tools such as Gazebo and UWSim were used to verify our design. The aforementioned camera mount, along with other in-house 3D-printed additional parts for our ROV, are also introduced below.

The following technical documentation presents the design rationale and development process of the creation of Fronteer.

Content

DESIGN Rationale 2

2.1 Design process

Understanding the task
To ensure our design fulfills the task requirement, all our engineers shall fully understand the specifications.

Brainstorming
To find out the simplest way to complete the tasks, we encouraged all engineers, including both junior and senior, with various technical backgrounds to propose their creative ideas even some of them may not be practical. During this stage, some surprising and innovative elements could be implemented into our design.   All engineers stayed together and fully involving in this stage.

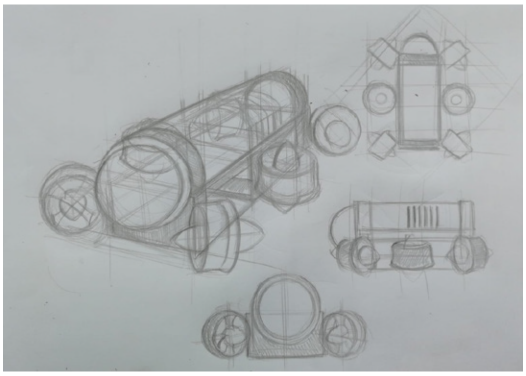


Fig.2 Hand sketch of ***Fronteer*** at Brainstorming Stage

Designing
Our designers created the first draft on papers.They explained their design rationale, for instance the working principles, to senior engineers in details on whiteboard.   Our engineers would provide feedback as peer review. This practice ensures our design being both innovative and feasible through collaboration.

Prototyping
In order to facilitate the prototyping, we created a CAD model with SolidWorks, which could be used in 3D printing and simulation in the following stage. The 3D printing provided an efficient way for our engineers to create a functional prototype with low cost.

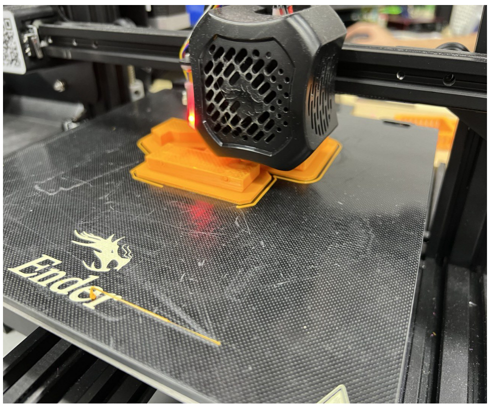


Fig.3 3D Printing Prototype of Camera Mount

Testing
The design was verified by computer simulation modelling.   SolidWorks had various simulation functions, for instance the fluid dynamic modelling. The simulations allowed our engineers undergo in-depth analysis on the physical properties of the design.   With the professional knowledge, our engineers could amend the design and make more reliable according to the simulations.The results would be also compared with the physical testing.

Modifying
The design was modified according to the pivot satisfaction, opinions of senior engineers and previous test data. The final design had gone through iterations of the design modification loop in order to ensure it could complete the tasks effectively and efficiently.

2.2 Mechanical

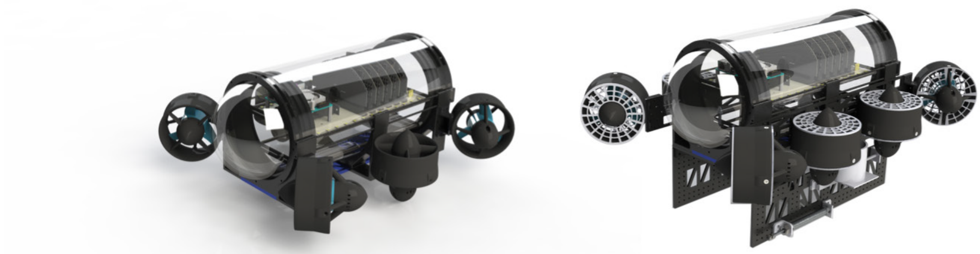
2.2.1 Design Evolution

Our team has always put high emphasis on improving the performance and functionality of the underwater robot. We have held reflective meetings and regular meetings to evaluate and brainstorm how to build and enhance our robot so it can reach our client's needs.

Our first step is to analyze the shortcomings from previous years to decide which parts we need to change and which parts we can keep. We consider using quick mounts to make the manipulator install or uninstall more efficiently. This mount can reduce the time of maintenance. On the other hand, our new camera mount is more flexible than the last type as it can rotate according to our needs now. Thus, this design can improve the view of ROV underwater.

2.2.2 Frame and structure

Based on the experience from the previous years, the frame has been modularized to accommodate for different mission. Reusing the frame does not only reduces the time of design, but also minimizes material waste. Depending on the specific requirements, the 6061 Aluminium frame can be configured into compact form or extended form as shown in Table 1, simply attach or detach the bottom payload rack as shown in Figure 4. For the grip point, lightweight carbon fiber rods were added for easy transport.



Year	Compact Frame	Extended Frame
Dimension (cm)	45 x 37.3 x 19	53.8 x 37.9 x 27.6
Weight (kg)	9	12

Table 1: Comparison on Compact and Extended Frame

Reviewing last year's frame material High-Density Polyethylene (HDPE), although HDPE is relatively lightweight, compact and flexible, the space is restricted after all the components of the vehicle are set up. In addition, the previous design fastens the screws using nuts, which make positioning and retrieval a time consuming task. These drawbacks conflict with our aim of having a vehicle that is convenient to set up, maintain, reposition and adding components.

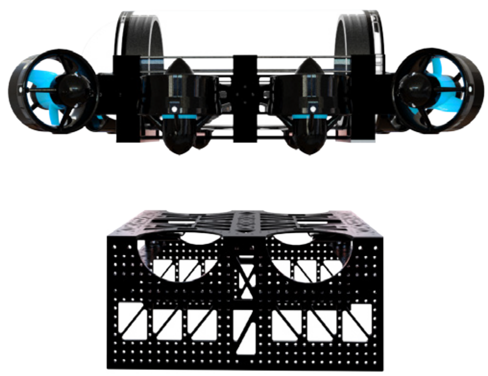


Fig.4 Exploded View of Side Frame

Although 6061 Aluminium Alloy is heavier and more expensive, it keeps everything modular as the frame have standardized threaded holes throughout which allows mounting extra components without reinforcement of screw nuts. Thus, minimizing the unnecessary component and time.

2.2.3 Electronic tube

The electronics housing is placed inside the tube. To completely seal the tube, CNC aluminum flanges with double O-ring design is implemented. Both ends of the acrylic tube are also sealed with double aluminum plate, acrylic plate and spherical cap. During assembly, the O-ring are pressed against parts which seals the interface thus waterproof the tube.

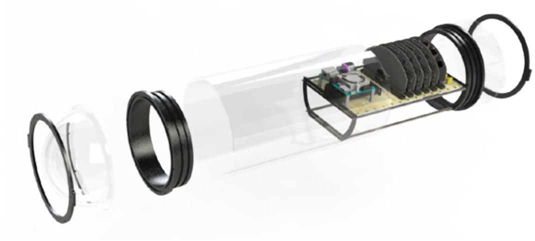


Fig.5 Exploded View of Container

For mounting of the electronic housing rack, four steel studs are chosen because of their standardized thread and strength. Two carbon fiber end plates are used to direct the stud head to the corresponding thread hole of the flange. It contains two level of slots, one is for the motherboard while other is for carbon fiber plate for daughter board placement.

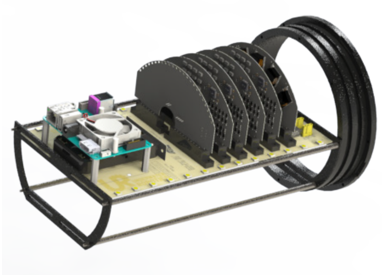


Fig.6 Electronic Housing mounted on Aluminium

2.2.4 Propulsion

The propulsion system comprised of eight Blue Robotics T200 in a vector configuration for achieving 6-DoF. Four T200 for Sway Surge and Yaw motion, and four T200 for Roll Pitch and Heave motion. With the autopilot system, the vehicle could have full control over its pose.

The maximum speed of the vehicle was tested to be 1.1m/s in our most recent testing.

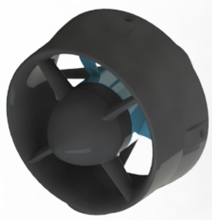


Fig.7 T200 Thruster

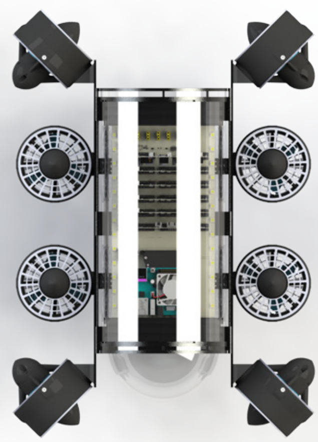


Fig.8 Thruster Configuration

2.2.5 Buoyancy

Since ***Fronteer*** has adopted a electronics tube design to store all electronics, it allow us to uses lead weight to achieve neutral buoyancy as the large volume of air from the tube provide positive buoyancy.

However, as the vehicle have multiple add-on components to cater different tasks, flexible adjustment of buoyancy is necessary. It can be adjusted positively or negatively buoyant by the use the Polyurethane (PU) Foam or lead weights accordingly. In the material selection process, our engineers have considered PU foam for its low water absorption rate and capacity, high resistance to compression as well as easy shape adjustment for maintenance and fine tuning. On the other hand, lead weight has a high density so it occupy an insignificant amount of space compare to foam, which is one of the plus in keeping the vehicle nice and sleek.

2.2.6 Pneumatic system

Fronteer's lifting arm, gripper, cover holder and lift bag are powered by pneumatic system, that is regulated to 40 psi (around 2.65 bar). The System Interconnection Diagram of Pneumatic System is attached in Appendix B.

2.3 Electronics

2.3.1 Design Evolution

After several years of implementation and development of a modular electronic structure, the modular system in the ROV tends to be stable and advanced. This year a more compact size of motherboard, more advanced daughter board system and CAN network are implemented into the ROV. These changes increase the interior space of the electronic tube and decrease the wire traveling distance, which can greatly decrease the assembly time of the ROV and also prevent the bad contact of the plugs.

2.3.2 Tehter

All camera signal lines and the power lines would be grouped into the tether cable with a 12 core waterproof aviation connectors plug. To avoid the clutter of the connection wires connected to the ground station and the vehicle, the pneumatic tube would be attached on the tether cable as the tether has tensile strength.

The tether itself was reinforced with Kevlar material to ensure a secure retreat of the vehicle under emergency. Moreover, in order to provide a secure attachment point for the tether cable and carry any tension directly to the vehicle frame, a steel wire connected to the vehicle and ground station at both ends as strain relief.

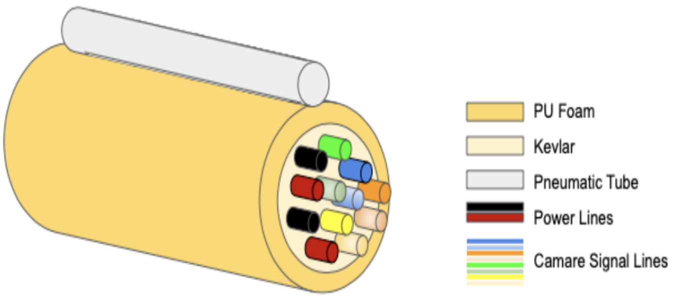


Fig.9 Tether Composition

2.3.3 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.

2.3.4 Power

Four Telecommunication-graded DC-DC buck converters are used for the power system on the ROV. Each Board will consist of two converters, which are connected in series. And the boards are connected in parallel. The voltage step-downs from 48V to 16.8V. The maximum output current is 90A, and the maximum power could be up to 1512W. The new power system provides better stability and less failure rate than the last version.

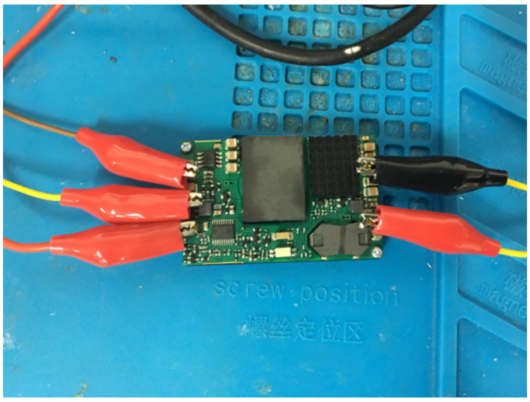


Fig.10 Testing on DC-DC Converter

2.3.5 Backplane

In order to improve management on different subsystems, a backplane is designed for Fronteer. The backplane is divided in three parts, Main Board, Rear I/O and Power board and the Single Board Computer (SBC) with autopilot. Defensively designed plugs and daughter board slots are used on the back-plane, plugs and all daughter boards could only be plugged in one direction, which avoid any human error in connection. To prevent overheating, a high efficiency heat dissipation design is also applied to the backplane.

Fig.11 ***Fronteer's*** Backplane

This new version of backplane have reduced the length of the PCB but remains the functions of the old version backplane, which free spaces in the housing. With the larger available spaces, Fronteer are able to upgrade a more powerful SBC or a ZED camera that usually need a large space.
The signal from SBC computer and autopilot will be connected to the main board by the specialized plug which is more reliable and secure, and it is easy to change to different SBC, as only have to change the connector on the SBC side.
There are a total of five daughter board slots for expansion. With the daughter board slots, a modular approach is demonstrated on the backplane. Each electronics sub-system has its independent daughter board that could be plugged on the backplane to share five power buses (12V x 2, 5V x 3) and four signal buses (I2C , UART, CAN) on the backplane. The first two slots are able to contact the PWM signal, which is for debug and control, while the last three slots are not able to contact the PWM pin which the pins are used for the I/O output.

2.3.6 Daughter board

2.3.6.1 Power Daughter Board

Power Daughter Board has five channels of high efficiency power converter to regulate the power buses on the backplane. Five switches are added on the board to activate each individual power channel. To achieve the high efficiency power conversion, shielded high current inductor, solid state capacitor and low turn on resistance, fast response time MOSFET were used.

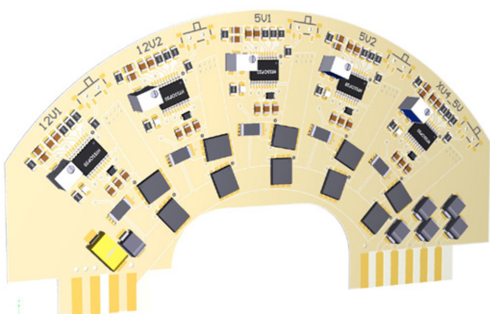


Fig.12 Rendered Power Daughter Board

Shielded high current inductor can generate less heat and less EMI to the whole system, while the solid state capacitor can work under high temperature environment. As for the low turn on resistance and fast response time MOSFET, they can significantly increase the efficiency.

The Power Daughter Board has been tested to achieve overall 90% efficiency in full load and 95% efficiency in normal situation. It can also operate in 100 °C testing environment for at least 10 minutes. This design is particularly useful under the condition when ***Fronteer*** is out of the water and under the sunlight.

2.3.6.2 Mainpulator Daughter Board

Manipulator Daughter Board is designed for the SBC to interact with different types of manipulation hardware. The board receives commands from the SBC through UART signal bus, then control different manipulator including pneumatic valve, servo, DC motor and electromagnet.

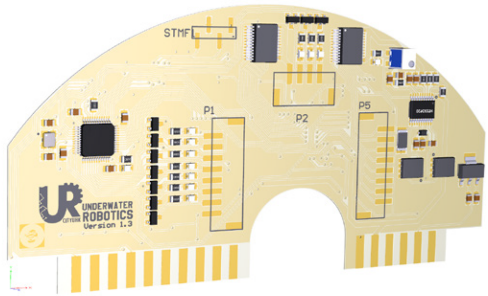


Fig.13 Rendered Manipulator Daughter Board

To handle incoming command, a register/command hybrid protocol is used to increase the flexibility of control. The former is used to store manipulator specific setting while the latter is used to respond command for controlling manipulator.

2.3.6.3 Camera and Peripheral Daughter Board

The main purpose of the camera and daughter daughter board is to specify video outputs to specific signal lanes. To take good advantage of the cameras, two servo motors are installed to be responsible for the camera rotation. As the servo motor could be powered up with 4.8V and the input voltage to the camera and daughter daughter board is 12V, the step-down voltage regulator would be used to output 5V for the servo motors.

2.3.6.4 Debug Daughter Board

The Debug Daughter Board is designed for fast diagnosis of the hardware system in the backplane . It provides various sensing measurements within the system, the voltage measurement of the power bus and thruster PWM status, the current consumption of the system and actuators. Apart from the system sensing , the system is capable of capturing all the data within the system communication buses. Once data is captured, the representing LED will be lit up to notify the pilot . Also, a LCD-monitor is embedded on the backplane to display the measurements, it provides a clear visualization to the system status of Fronteer.

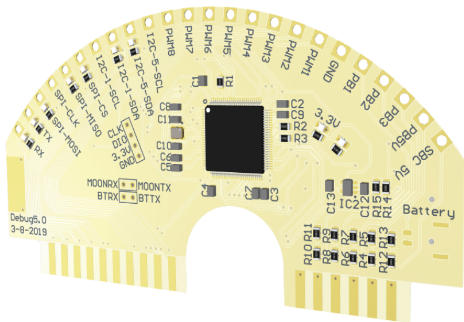


Fig.14 Rendered Debug Daughter Board

Besides, the data logger system is implemented into the debug system for storing and capturing the power and communication status of the system. The data will be directly logged into the SD card for future analysis, the data logger can significantly help with the debugging of the system . To prevent unexpected power failure ,the board is connected to a button battery in case any power failure happens on the backplane system, the debug system is able to run for a short period.

Moreover, the daughter board is designed with test holes on the edge of the board. The test holes are connected to power buses, signal buses respectively with designators clearly indicated beside the hole. Engineers can directly connect a logic analyzer or oscilloscope to the test holes to retrieve the signal of the system, which speeds up the maintenance and debug time.
Last but not least, engineers can connect to the debug system through bluetooth to view the decoded message in the communication buses. Such design could allow engineers to understand the status of the vehicle by visual indication, minimizing the risk of opening the watertight compartment.

2.3.7 Electronic Speed Control (ESC)

To control and regulate the speed of the thruster, eight 20A ESCs were used in ***Fronteer***. With traditional sealing method, the temperature of the ESC reached up to 150°C, which is not ideal for prolong operation.

To prevent overheating and reduce risk of accidents, our engineer designed to integrate a heatsink with heat conductive epoxy with the ESC. The ESCs are located outside of the electronic tube to allow additional cooling by water passively. The above measure lowers the ESC's temperature significantly, it's about 60°C in air and not higher than 40°C in water.

Fig.15 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

2.3.8 Vision

To provide different view angles for pilots to complete underwater tasks, five auxiliary cameras were installed onto the Fronteer, including one digital camera and four analog cameras. The digital camera was used to complete computer vision tasks. It is the primary camera for the pilot. The other four analog cameras were task-specific cameras, each of which was placed and designed based on different task requirements. Analog cameras were also used to provide multiple angles of view for the pilot to do precise movements. Analog cameras are also sealed together with the 12V to 3.3V regulator, resulting in a compact size and easy to place in different positions.

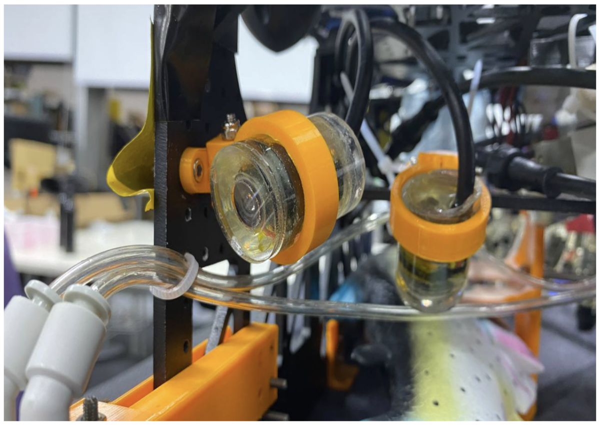


Fig.16 Waterproof Analog Camera

2.4 Software

2.4.1 design evolution

Since entering the stage of stable development, software on the Fronteer are designed upon the basis of three principles: Consistency, customizability and least-dependency.

Consistency: we always ensure the packages performing different functions to have the equal level of convenience when it comes to installation or removal of the package on top of the main framework. Each software package has to follow the same structure so that developers can have quick and easy access to different aspects of the code, for example environment parameters, source code, installation scripts, documentation etc.

Customizability: all software packages allow passing in parameters on launch so that the functional behavior can be calibrated according to the parameters encoded in a file. For example, the operator can choose to load a parameter file to tune the characteristics of the image retrieved from the camera, e.g. exposure, saturation, gamma etc.

2.4.1 design evolution(Cont.)

Least-dependency: we tried to keep every functional package dependent on the least number of other functional components, so that failure or miscalculation of one software package would induce the minimal damage to the entire system. For example, on every launch of a software package an environment check will be performed before importing a certain library, and the software would still run even if the required package was not installed, but the incident will be recorded in the system log for inspection by the developer afterwards.

2.4.2 Robot Operating System (ROS) Framework

ROS Framework was chosen since it could provide a decentralized network across all nodes. The communication among pilot, computer and ***Fronteer*** could be done under the ROS framework, in the form of messages and client-services, which greatly facilitates the sub-system development of ***Fronteer***.

Apart from providing efficient communication among the nodes and sub systems, the ROS framework also offers a platform for different programming languages' integration which are essential to our robust system, such as C++ and Python. Moreover, it reduces the errors caused by buffer overflow through controlling the rate of messages.

The internal libraries provided by ROS simplifies the design process. The debugging function in ROS helps engineers to tackle errors and modify system design with ease.

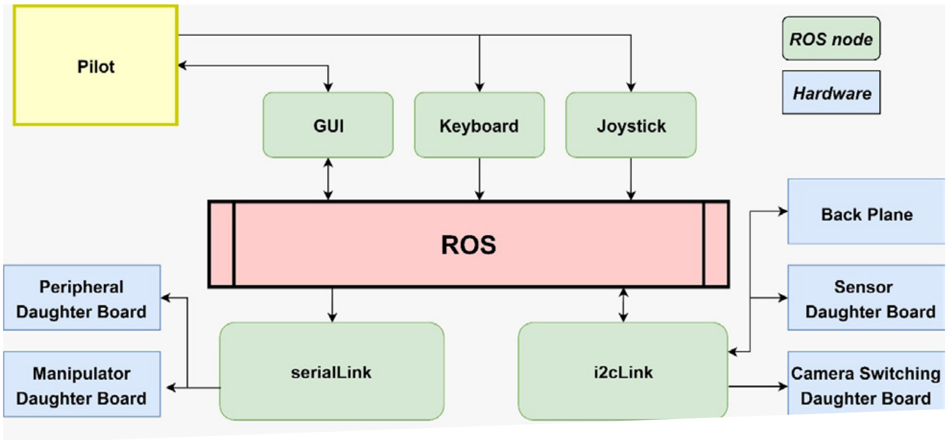


Fig.17 ROS Framework

2.4.3 Graphical User Interface (GUI)

The use of a graphical user interface (GUI) is to build communication between user and the robot so that users can understand how the robot is running as well as to control its components. This year, a different way is chosen to build the GUI in the Robot Operating System (ROS). To modularize the development, design on the user interface (UI) and coding on the communication are separated, which is achieved by integrating a user interface into ROS's GUI framework rqt. In practice, it is to write a rqt plugin package in ROS using an external user interface file (.ui).

Each node in ROS is defined as a package. The node produced by the rqt plugin package can also be a publisher and a subscriber in ROS's communication network. As a result, the node can listen to signals from the GUI and publish them to other nodes (e.g. joystick and camera), as well as collect message from other nodes and modify the values displayed in the GUI, which serves as a good middleman and forms a complete channel between the GUI and the other nodes.

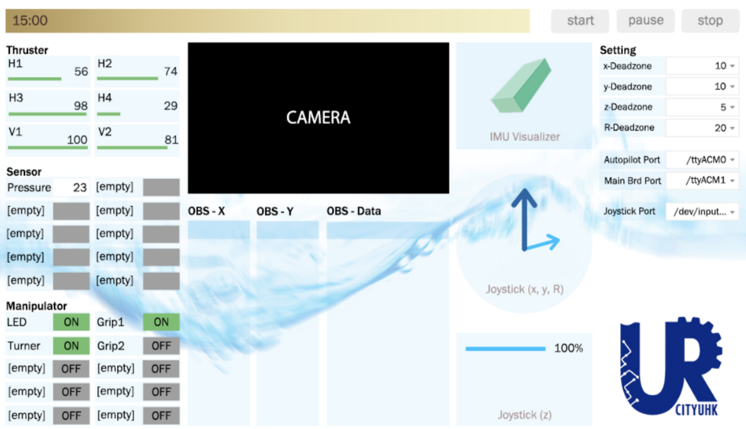


Fig.18 GUI Interface

2.4.4 Control simulation

UWSim, Gazebo and ROS were combined to carry out simulation on visual, physical and communication.

UWSim is an underwater simulator uses an open source 3D image rendering software, OpenSceneGraph(OSG) for realistic underwater scenes with color change of objects, visibility and other characteristics. Blender, a 3D model is opted to build and modify objects. To create realistic props, different functions including texturing, UV unwrapping and material simulation can be applied, which help to obtain testing data with higher accuracy thus improve the performance of computer vision algorithm.

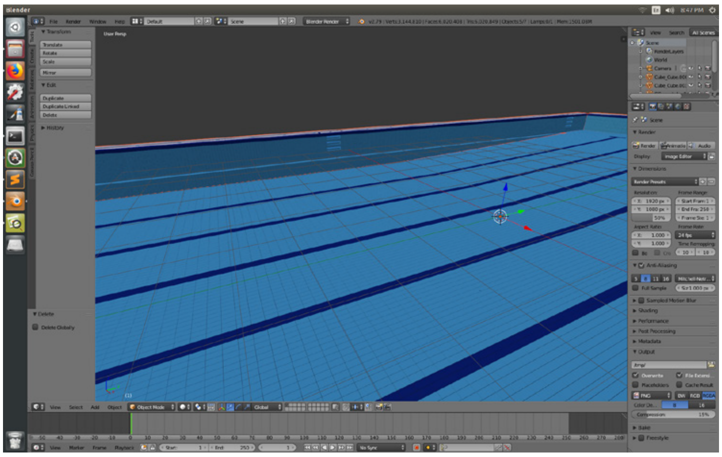


Fig.19 Virtual environment created with Blender

For Gazebo, ***Fronteer*** is replaced by a simple mesh to reduce computation required by the physics engine that improves the real time factor of simulation, allowing more computer resources free to be allocated to advanced autonomous control and image recognition. In addition, higher efficiency in simulation can be obtained as less detail is required to be rendered.

ROS is the bridge to combine image and control. Gazebo publishes messages of object states while UWSim subscribes the messages to render new frames. The camera images captured are also used for image recognition and published to the control program for calculating the upcoming actions. Once the next action is confirmed, control messages are sent to Gazebo to move the vehicle to perform autonomous tasks in a simulation.

2.5 control Station

The control station of the ***Fronteer*** was made by the modified pelican case. This portable device has large capacity which allowed the peripheral of the ***Fronteer*** well-organized. Since the design is made by the modified pelican case, it can improve ***Fronteer's*** the protection of the peripheral in terms of transporting.

Besides, the control station was also equipped with router and different types of controller for different situations. The software of the control station was programmed, hence it could accept Xbox360 Joystick and Logitech Flightstick.

Fig.20 Control Station of ***Fronteer***

2.6 Mission specific tools

To complete tasks request by the Eastman, ***Fronteer*** is equipped with customized tools.

2.6.1 Manipulator

2.6.1.1 Quick Mount

The quick-mount consists of two parts, a mount, and a plug-in. Mount is permanently mounted on the ROV with L-shape holes .While the plug-in is merged into the mount by the L-shape stand. Besides, in order to achieve the locking feature, a piston is located inside the mount with a slingshot Installed. The piston will be pushed outwards by the slingshot unless there is a manual pressing action or plug-in performed. As a result, we can reassemble our preferred manipulator for each designated task quickly by pushing the plug-in into the mount and dismount the plug-in part by pressing the piston . Once the plug-in is fitted into the mount, the piston will be released and pushed outwards by the slingshot, then the piston will be locked and stabilized into the plug-in and its corresponding manipulator. This will become one of our design standards afterwards, mountable manipulators can integrate with the quick mount design. As it can significantly increase the flexibility and efficiency of the assembly and maintenance of the manipulator.

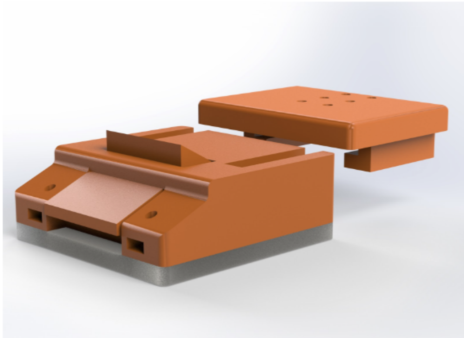


Fig.21 Rendered Quick Mount

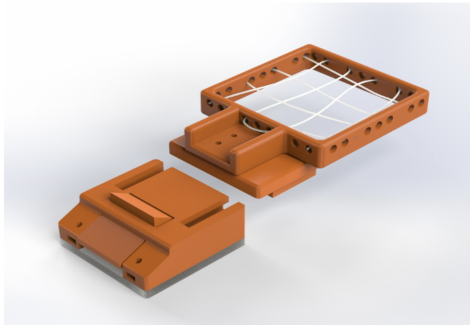


Fig.22 Rendered Example Plug-In

2.6.1.2 Pin Catcher

The Pin Catcher is designed for general pin-catching purposes, especially for pin-removing operations in tasks 1.1 and 1.3. The inlet area is 70mm * 70mm squares with multiple holes on the frame. Fish twine is used to go through these holes and construct a net with density depending on the choice of the holes. If more holes are wired, the void in the net will be smaller.

The mechanism of the pin catcher is simple. When the ROV moves toward the pin, the head of the nail will enlarge one of the voids by deforming the fish twine and going through the net. After the head of the pin goes entirely through the net, the net will contract to its standard shape by the tension. When the ROV moves apart from the pin, the hook is trapped by the fish twine and can no longer escape from the net. Thus, the pulling action is achieved. After testing, the wiring structure shown in Figure X is the best fit for the size of the pin used in the tasks. Also, this device is compatible with the use of the quick-mount device. Once the pins are all pulled out, the Pin Catcher can be swapped to another manipulator easily and quickly at the poolside.

Fig.23 Rendered Pin Catcher

2.6.1.3 Fish Clamp

In order to securely remove Morts from the bottom of the fish pen, two actuators were combined to restrict the 6 DOF of the fish.

A Fish Clamp with vertical wall and bottom, were designed to remove the fish. Two vertical walls with curved sweep were pushing toward each other, two horizontal layers on the vertical wall, providing a firm grip to prevent the fish from dropping off, and securely holding the fish. The fish clamp will restrict 5 DOF of the fish. Three extra assisting arms were also installed to align the head, belly, tail position of the fish, preventing any tilting motion from the fish. Providing an extra DOF restriction.

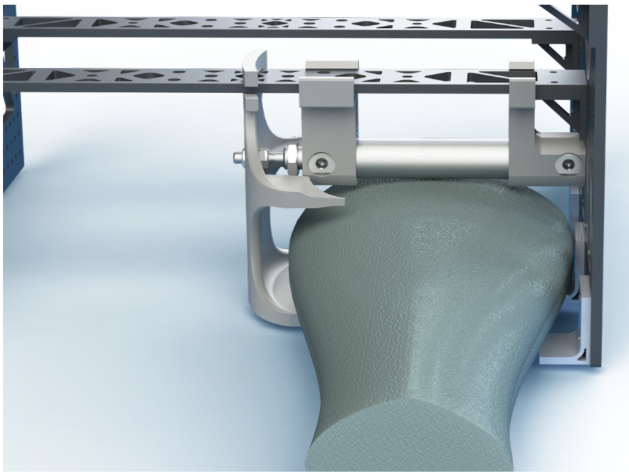


Fig.24 Rendered Fish Clamp

2.6.1.4 Grasp Finger

The finger is used to grasp the seagrass and other suitable objects made by water pipes. Two grippers are placed under the main tube and installed on the left and right sides of the rack. The gripper assembly comprises 3D printing parts made by PLA and powered by a pneumatic finger. We use a pneumatic system rather than a DC geared motor system because a pneumatic system requires less maintenance. All pneumatic parts can be controlled by one control valve.
In contrast, a DC geared motor system needs an independent system for each gripper. On the other hand, a DC geared motor gripper needs lots of small components to form a complete gripper, and every minor modification may lead to redesign. However, we can make a mold of the gripper and install it on the pneumatic finger.
The finger has sawed jaws, which can increase the friction between the finger and the object in case the object slips during the movement of ROV. It is used to pick up seagrass. The hole behind the saw jaws is used to catch water pipes like cable. One gripper is vertical, and another is horizontal to handle different tasks.

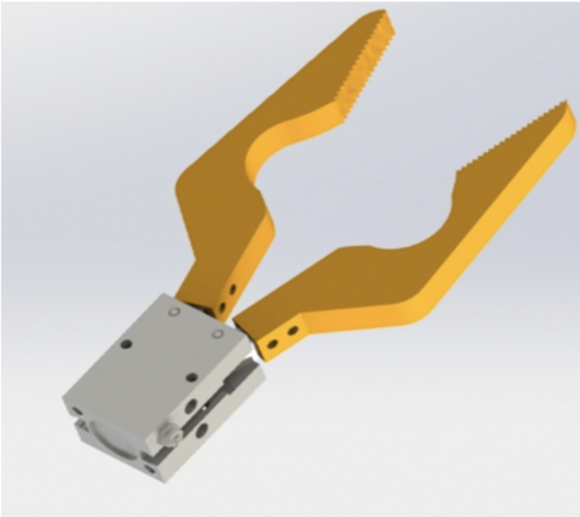


Fig.25 Rendered Grasp Finger

2.6.1.5 Camera Mount

A new camera mount has been designed. This camera mount consists of three parts: the camera mount at the top, pit angle mount at the middle, and yaw angle mount at the bottom. This two-angle mount has a hexagonal pit to hold the angle in place compared to friction firmly. The screw can adjust the ease of moving the camera angle. As a result, a 180-degree view can be achieved with this mount. And the angle of view can be adjusted easily by directly turning the camera with hands, and the hexagonal pit will still hold the angle view in place.

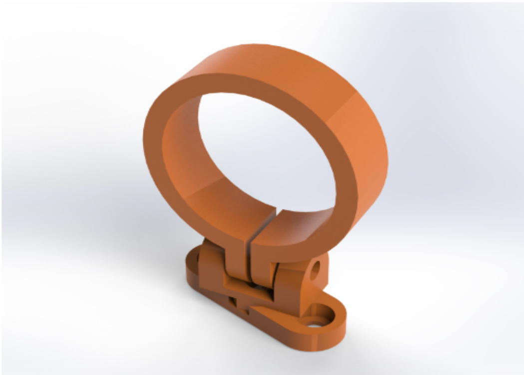


Fig.26 Rendered Camera Mount

2.6.2 Buoyancy Engine

The engine is built with a watertight enclosure and external buoyancy support. The internal components are six syringes, one stepper motor, one customized PCB, and eight A23 batteries. All components are mounted individually on 3D printed mounting plates and a box. Individual batteries are stored in a power box at the bottom of the enclosure, which helps concentrate the center of gravity at the bottom for stable vertical profiles. A special design motor mount separates the motor from the power station and gives extra support to the heavy weight. The layout of the enclosure is supported by 3 hollow aluminum rods. The external buoyancy support consists of 4 PVC tubes, 4 acrylic boards, buoyancy foams and weights. Epoxy waterproofing is done at the syringe heads and sensor ports to ensure safe operations. In advance, the height of the engine would be within 500mm, with a maximum diameter of 175mm.

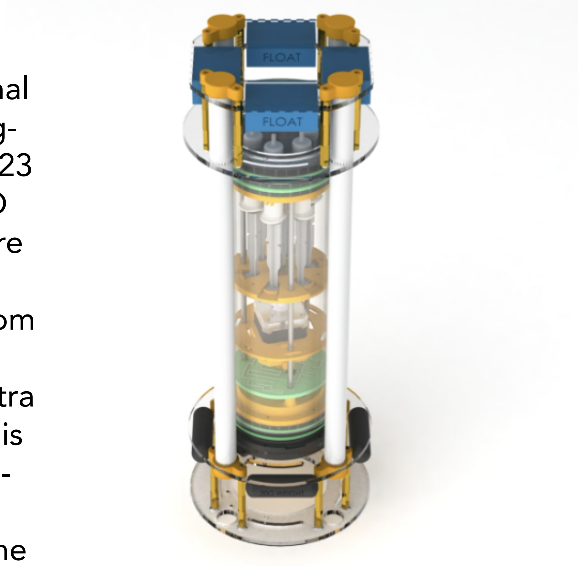


Fig.27 Rendered Buoyancy Engine

2.6.2.1 Linear Motion System

A vertical profile is driven by the stepper motor controlled by PCB. Syringes are mounted and locked on the upper top of the watertight enclosure by two 3D printed plates. Plunge movement is controlled by the stepper motor through a leadscrew. Leadscrew connects the plunge plates and stepper motor and translates the turning motion of the stepper motor to the linear motion of syringe plunges. The lead screw is paired with a nut to prevent backlash and fix the position of the plunge plate.

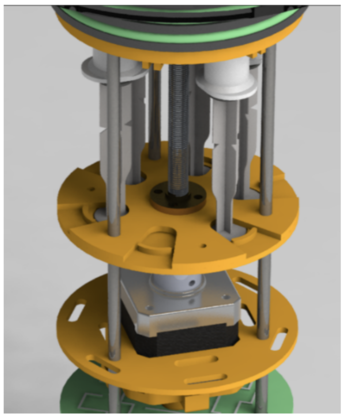


Fig.28 Rendered Linear Motion Module

2.6.2.2 External Buoyancy Support

The float is in neutral buoyancy before any operations. An external frame with foam and weight is therefore added externally. The frame is made up of 4 acrylic plates connected by copper stands. 4 PVC tubes serve as the main supports of the external frame and handles for ROV manipulation. To detect the ROV contact as program input, pressure sensors are inbuilt on the PVC tubes.   Both foam and weights would be fixed with zip ties.

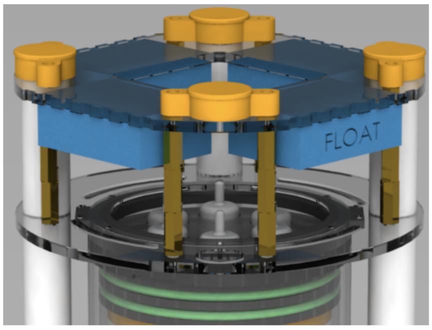


Fig.29 Rendered Buoyancy Float

2.6.2.3 Special Mounting Design

The entire system required support in the bottom to settle down the fixture of most of the components, including shafts and motor. For convenience, a box that contains a battery sits on the bottom of the tube, the top plates of the box with special shape are the stands for motor mount, holes for allowing the shafts to glide in, and for supporting the circle PCB. While inside the battery box, there would be two sections with each section containing 4 batteries, where the two sections are separated by an acrylic board. The 3D printed box contains 4 extruded boards to store the battery in place. For connection, different slot holes are made in all components of the box.

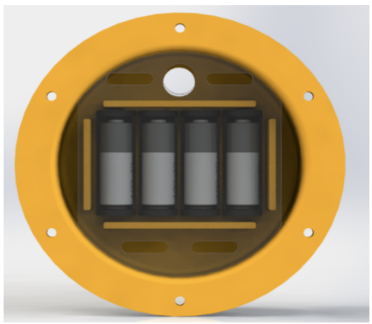


Fig.30 Rendered Battery Mount

Safety 3

3.1 Safety Philosophy

Safety is prioritized in CityUUR. Our company considers the safety and health issue of our fellow members in every task we have done. ***Fronteer*** is a well-design vehicle which fulfill safety requirement and standards, in such way it could minimize risks of injury of our members during operation as well as logistics of the vehicle.

Creating a safe working environment for our fellow members is critical as well. Our company designed different safety protocols for our members, they need to adopt suitable protocol under different situations like constructing ROV or during operation of ROV.

3.2 Safety features of ROV

Our mechanical engineers ensured that ***Fronteer*** is safe to handle by adopting various safety features to minimize risks to crew and threats to the environment during its operation:

- All moving parts and hazardous components are **labelled with eye-catching labels** which are noticeable to any users.
- **No sharp edges** are exposed during the main frame construction and other hardware components' manufacturing.
- The **propellers are protected with shrouds**, which protects user 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 emergency or any abnormal operation situation.

Apart from hardware safety measures, our software engineers also developed several system to monitor ***Fronteer's*** status to prevent any unstable situation:

- **Fail-safe system**, which recalls the ***Fronteer*** to surface once the connection is closed. The measure could prevent the loss of vehicle during its expedition. A signal would be sent to onboard LED strip which indicates the status of vehicle in the form of patterns and colors, for instance 'Power On', 'Bug Detected', 'Performing Mission' or even 'High Current'. The pilot could make decision according to the status shown.

- **Power Management Unit with 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 emergency, ECPO can be activated in two mode depending on the situation to cut of power to the thruster only or the whole vehicle.

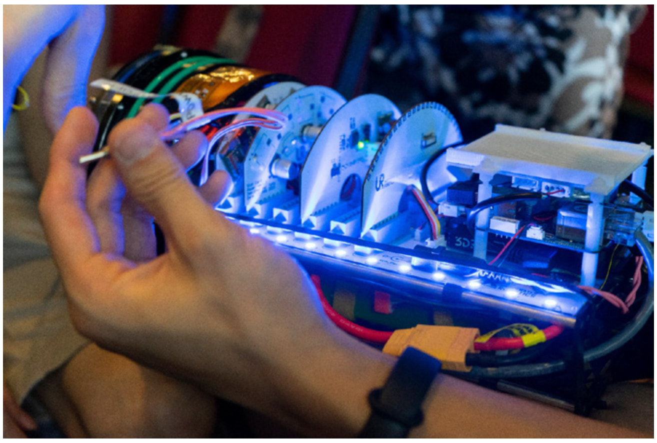


Fig.30 Backplane with Fail safe system and LED Display

Safety

3.3 Operation Safety Protocol

Our operators are required to fill in a safety operation checklist (attached in Appendix C) before, during and after any operations. With this standardized procedure, operators could check the functions and status of ROV, which protects them from potential risks or injuries.

3.4 Lab Safety protocol and Training

CityUUR organizes compulsory lab training sessions every year for new members to familiarize with workplace safety and lab practice. Each training session consists of two hours. Senior engineers would demonstrate safety measures, including usage of personal protective equipment (PPE), proper machine usage and emergency training. Peer evaluation will be conducted during training session, to recognize the safety of ourselves and other's. In such practice, each member understands safety measures at workplace, which truly prioritizes 'safety' as the core value of our company.

To ensure a safety working environment, a Job Safety Analysis (JSA) form and PPE are required for member to review and use before performing any heavy machinery, to minimize the potential risks and threats to members.

Fig. 31 Peer Training System when performing heavy machinery

Logistics 4

4.1 Project Schedule

At the beginning of October, the project manager and department lead set up a schedule for the project, which helps to keep track of the deadline and the goal that our company want to reach. Detail schedule is added after mission specification is released.

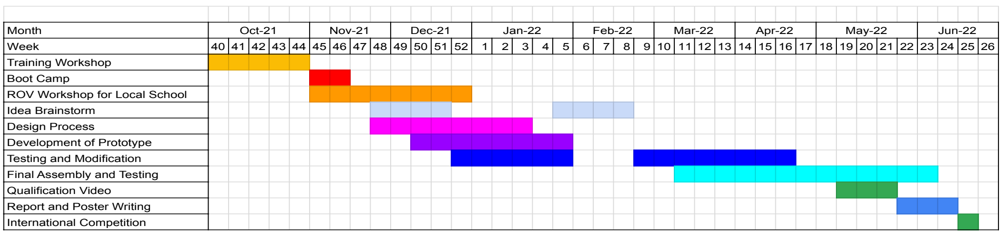


Table 3: Work schedule of ***Fronteer***

4.2 Company Structure and project management

CItyUUR is divided into four departments, namely Mechanical, Electronics, Software and Public Relation (PR). This simple but effective organization structure ensures the best project management and development.

Each member is assigned to different departments according to their technical background and strengths. Each department has an engineer lead, who keep track of the project progress and ensures proper labor division. The project is supervised by a project manager, who monitor the progress of project, division of labor, budget and costing. The CEO oversees the whole project and give a proper direction for the company.

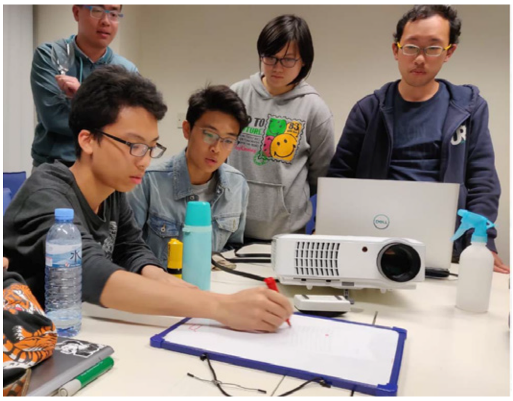


Fig.32 Idea brainstorming during weekly meeting

Along the whole project, department and cross department meeting are hold regularly to keep the team engage. In such way, each department could fully contribute to the project and accomplish it by collaboration.

To ensure efficient job allocation, project manager would put employee's ability into consideration to match the nature of the task. For instance, member who is familiar with CAD drawing as well as having mathematical background for ROV frame designing. On top of that, employee's availabilities is also taken into account. We ensure each member contributes to the project by having even labour division, which is an alternative way for quality assurance of tasks. The job allocation practice also gives opportunities to junior members involving in this project

4.3 Management Platform

CityUUR used various platforms (they are Google Drive, Git Server, Freedcamp, Wordpress and Toby) to manage the progress of different tasks as well as maintain a good information flow among all members.

By using Freedcamp and Wordpress, we can manage and work according the project schedule through setting up target-to-meet and monitoring the progress by checking each member's regular logbook update.

With Google Drive and Git Server, members are able to edit the documents online simultaneously, which is essential for team collaboration. Files are automatically updated in real-time without delay, such that all members can access the most up-to-date information, which is critical for information flow.

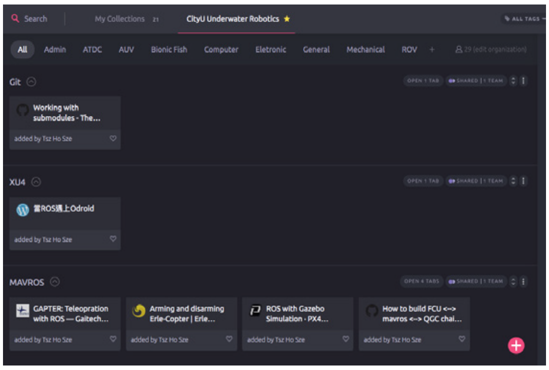


Fig.33 Toby for learning

Toby is used to create a self-learning platform, which members can share useful resources. We encourage members to gain different knowledge or searching answers by themselves. At the same time, we also hope members improve the problem-solving skills through this kind of daily practice.

4.4 Project budget and expense

Fronteer's budget is set at the beginning of the year and estimated according to previous project, which covers cost of ROV construction, MATE Competition and team's daily operation. In this year, the major expense is mechanical and electronic system, for the electronic housing and development of a new backplane system which require some trial and error.

With limited resources, financial planning and monitoring is essential. Each department have a strict budget to follow and purchase will be reviewed and approved by the department lead, and receipts will be recorded into monthly expenditure list for tracking purposes.

Project Expense and Budget - FRONTEER - CityUUR 2022 ROV						
Category		Item/Expense	Type	Amount	Total Amount	Budget Allocated
Mechanical	Structure	Alminium Frame	Purchased	$451.00		
		3D Print Filament	Purchased	$62.00		
		Waterproof Compartment	Purchased	$150.00		
	Pneumatic System	Pneumatic Valve	Reused	$129.90		
		Pneumatic Cylinder	Reused	$33.60		
		Pneumatic Tubing	Reused	$12.40		
	Others	Epoxy	Purchased	$48.20		
		Hardware Miscellaneous (Screws)	Purchased	$36.10		
		Polyurethane Foam	Purchased	$9.90	$933.10	$900.00
Electrical	Power	48V to 12V Regulator	Reused	$49.90		
		Adjustable Output Regulator	Reused	$10.00		
		Anderson Plug	Purchased	$4.90		
		Fuse	Purchased	$2.70		
	Core System	Auto Pilot	Reused	$37.90		
		Micro-controller	Purchased	$19.80		
		Video& Internet Transceiver	Reused	$29.90		
	Propulsion System	Electronic Speed Controller	Purchased	$23.50		
		T200 Thruster	Reused	$1,291.00		
	Vision System	Analog Camera	Purchased	$19.20		
		LED	Purchased	$5.00		
	Peripheral & Sensor	Servo	Purchased	$4.10		
		Pressure Sensor	Reused	$71.00		
	Others	Miscellaneous (Resistors, Capacitors, Inductor…)	Purchased	$65.80		
		Printed Circuit Board	Purchased	$128.80		
		Waterproof Connector	Purchased	$30.00		
		Wire	Purchased	$2.10	$1,795.60	$2,000.00
Software	Control System	Single Board Computer	Purchased	$53.00		
		Controller	Reused	$25.30		
		USB Capture Card	Reused	$9.90	$88.20	$100.00
Total Amount of ROV Construction					**$2,816.90**	**$3,000.00**
Competition Expense		MATE Registstration Fee & Fluid Power Quiz	Purchased	$165.00		
		Mission Props	Purchased	$154.00		
		Airfare (for 9 employee)	Purchased	$17,198.19		
		Hotel (5 nights 6 days)	Purchased	$3,398.90		
		Team Transport Expense	Purchased	$901.98		
		Poster Printing	Purchased	$27.80	$21,845.87	$20,000.00
Total Amount of Competition Expense					**$21,845.87**	**$20,000.00**
Operational Expense		Equipment	Reused	$278.00		
		Team Apparel	Purchased	$175.00		
		Pool Renting	Purchased	$965.00		
		Promotional Material	Purchased	$33.00		
		Transportation	Purchased	$42.00	$1,493.00	$1,700.00
Total Amount of Operational Expense					**$1,493.00**	**$1,700.00**
Income		Department of Computer Science, CityUHK	Cash	$3,260.00		
		Department of Electrical Engineering, CityUHK	Cash	$10,620.00		
		Department of Mechanical Engineering, CityUHK	Cash	$4,260.00		
		Student Development Services, CityUHK	Cash	$5,670.00		
		Member Dues	Cash	$1,000.00		
		Alumni Donation	Cash	$1,560.00	**$26,370.00**	**$24,700.00**
Total Income for 20/21					**$26,370.00**	**$24,700.00**
Total Raised (USD)					$26,370.00	-
Total Spent (USD)					$26,155.77	
Net Blance (USD)					$214.23	

Table 4: Project costing and budget

Conclusion 5

5.1 Testing and troubleshooting

Testing is a critical stage which verifies our ideas and design through real practice. Objective analysis and comparison among prototypes are needed for evaluation as well as decision making.

We built a few prototypes based on different designs or ideas and went through different testing. At the beginning, we tested each component independently for checking their performance. This individual testing allows us to have a better understanding on the functionality and stability of each component, which is critical in system design. We also utilized different simulation tools, for instance Gazebo simulator and SolidWorks. The SolidWorks can simulate and check the hardware functionality; while the Gazebo simulator can test the software of the vehicle. Testing with simulation tools can save time and money, comparing to constructing real models. They can output reliable results with minimum effort.

However, there may have some errors in simulation which are not preventable, such as the round off errors and truncation errors. Therefore, pool test in reality is needed to figure out the performance and practicality of ideas and design of our vehicle. Parameters, including stability, efficiency, buoyancy, manipulation and the overall performance are taken account in pool test.

A systematic and logical flow is created for tackling the problems based on trial-and-error approach while fulfilling the safety requirement. The following figure shows our troubleshooting approach.

Fig.34 Approach of troubleshooting

The vehicle may not meet our expectation during testing due to various undesirable factors. Therefore, we simulated the scenario for several times in order to identify those factors. Then, we referred to the original concepts and fundamental theories so as to eliminate those undesirable factors. Next, we conducted tests again to check the validation of suspicion. Finally, we modified the design by altering the design.

5.2 Challenges

Technical
This year we have built our first modular backplane which integrated every sub-system. In such a high density environment, noise reduction and thermal performance is the biggest challenge this year. One of the solution to reduce noise is to separate the power and signal on the PCB design. As such, our electronic engineer have done a series of PCB iteration for different method on hardware isolation to lower the noise level, which our engineer has successfully reduce it to an acceptable level.

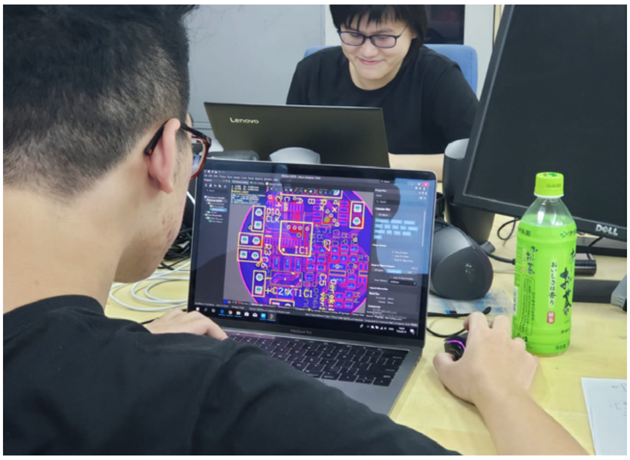


Fig.35 Electronic Engineer drawing PCB

Fig.35 Iteration of PCB

However, our engineer observed that the heat generated from the power system and external heat sources cause some 3D printed parts in the Electronic Housing to melt when the vehicle is place under the sun for an extended period. Different cooling method has been tried to prevent overheating but the best solution is yet to find. In order to ensure the system remain stable under high temperature, oven test has been done to all our PCB to make sure it can remind functional in 100 °C for 30 minutes.

Non-Technical
CityUUR is an organization which consists of more than 30 members. Team management is always one of the challenges such as communication and labour division. By using various platforms mentioned, such as Google Drive, information flow can be maintained. Members can access the most updated files and work on the files simultaneously for better collaboration. Freedcamp can set up schedules for members to follow, ensure the progress of the project on track as well as even workload for each member.

Resources, including money, is another challenge in this project. With limited budget, purchases of some components may be off-schedule due to insufficient cash flow, which slows down the progress of the project. Having a good financial planning is one of the solutions. Items are purchased according to their priority, based on current cash flow and availability of product. Fundraising will be an alternative. Our company looks for sponsorship and donations through organizing different activities such as workshops.

5.3 Lesson learned and Skills gained

Technical Lesson Learned
As mentioned earlier, a modular electronic system was used this year, all peripheral system has been integrated to daughter board and main system has been integrated to the backplane. This system was built based on one master template, where other circuit are developed following this. Our engineer realize that the master template is very beneficial to the

whole workflow and eases a lot of process since it allow engineer who are less familiar to the whole electronic system to be able to work on a particular sub-system. Extensive simulation are also conducted throughout the mechanical design process on the manipulator and frames, to testify the design before manufacture.

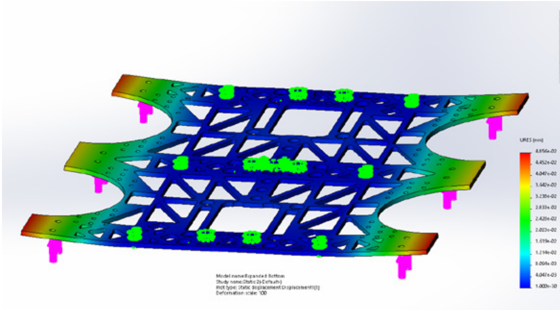


Fig.37 Stress Test on Side Frame

Interpersonal Lesson Learned
Each year, new engineers are recruited into the company as Juneer team. Bridging the gap between junior and senior members is often hard as they are in an unfamiliar in a new environment with different culture and background of people. Therefore, boot camp and ice-breaking session has been held to increase the interaction between junior and senior engineers to increase sense of belonging and eliminate the gap between them to create a vibrant team spirit.

Skills Gained
As it is the first year using an electronic tube to store all electronics instead of epoxy seal for each electronic component, our engineer has came across some new waterproof technique associate with the use of the housing. For example, using CAT cable to solder onto a waterproof plug and apply epoxy at the plug end as a double safety. Besides, in order to handle optic fiber breakage, fiber splicing technique is also acquired to most of our engineer.

5.4 Future Improvement

Design
In-house develop component is certainly one of our goal for future project, for example Field Oriented Control (FOC) ESC, as FOC can provide a higher accuracy and efficiency control on thruster, especially under low RPM, achieving micro-maneuver for better precision. Moreover, in-house develop on auto-pilot. In the current commercial product that we adopted, its functionality might not be suitable for future development. Therefore, there is a need to design a comprehensive design that is most suitable for our development. Finally, in-house develop of optical fiber transceiver based on FPGA is also one of our consideration. The product available in the current market is large and contain many unnecessary part. There is a need to custom made for function and size reduction.

Design Process
Since this is the first year for using multiple simulator, there are rooms for improvement. Through exploring the functions and usage of the simulator, we wish to master it before the next project. As simulator provides reliable simulations which resembles the actual environment, it can greatly facilitate design and development progress, especially for prototyping and testing. Even so, the experience of using simulator for ***Fronteer*** is very valuable, which provided a good reference for future projects.

Project Management
To achieve better project management, get knowing each member's strength and weaknesses 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 in familiarizing the pace of the team. This can achieve better management in terms of task distribution and manpower mobilization, thus foster effective collaboration.

Acknow-ledgement 6

CityUUR would like to express their appreciation to:

MATE Center - For organizing the MATE International ROV Competition 2022
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Fig.38 Acknowledgements

Reference 7

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Maxim Integrated. DS18B20
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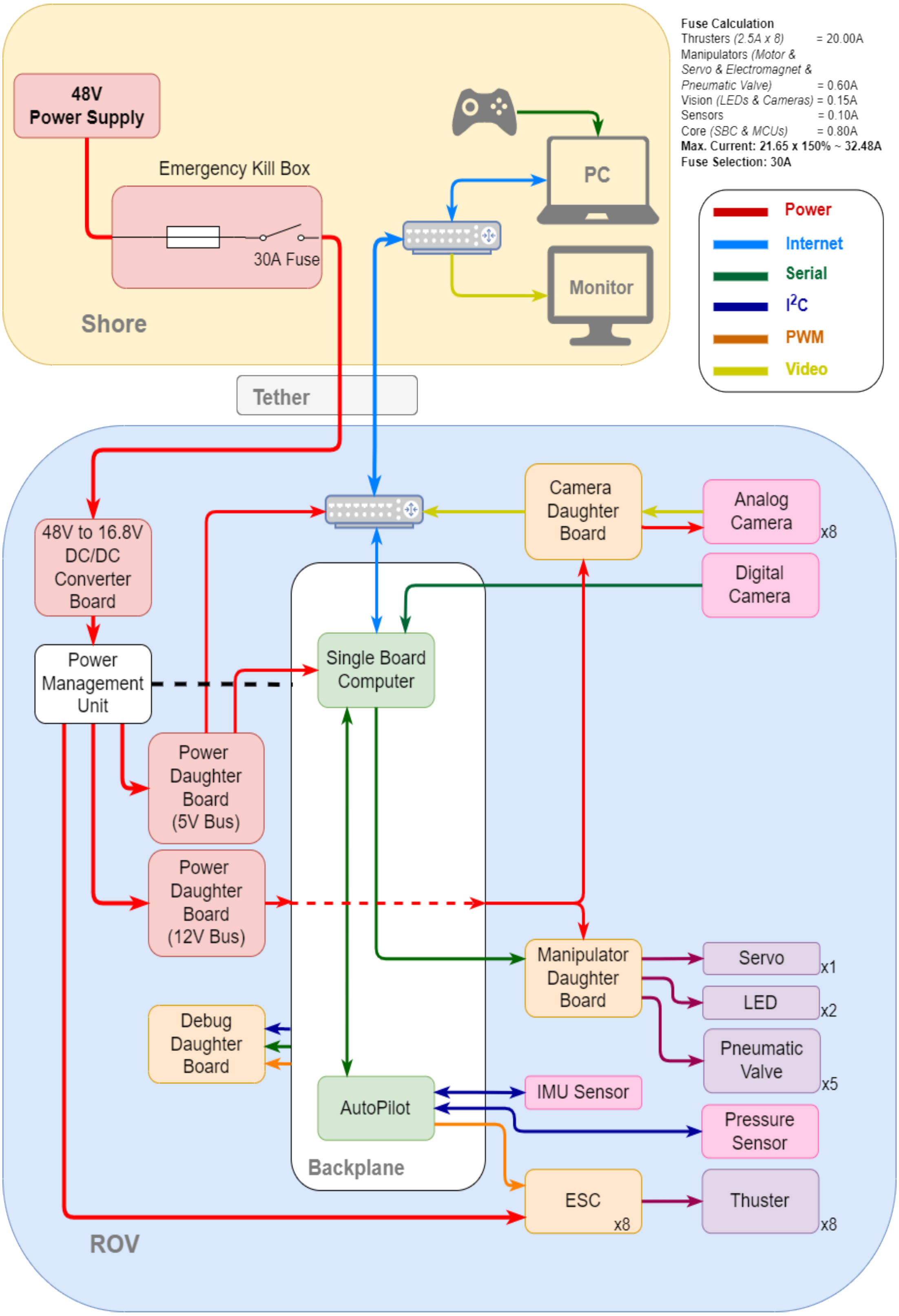
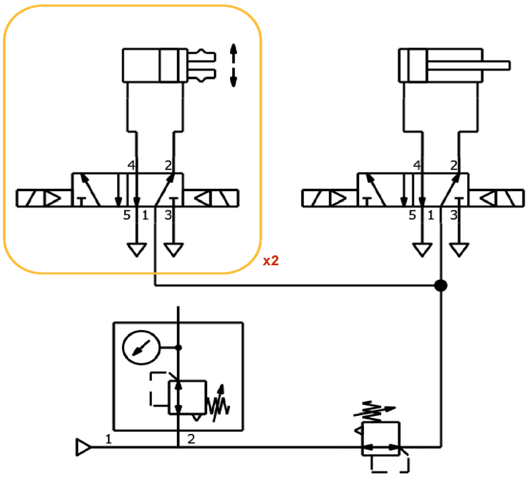
Appendix 8

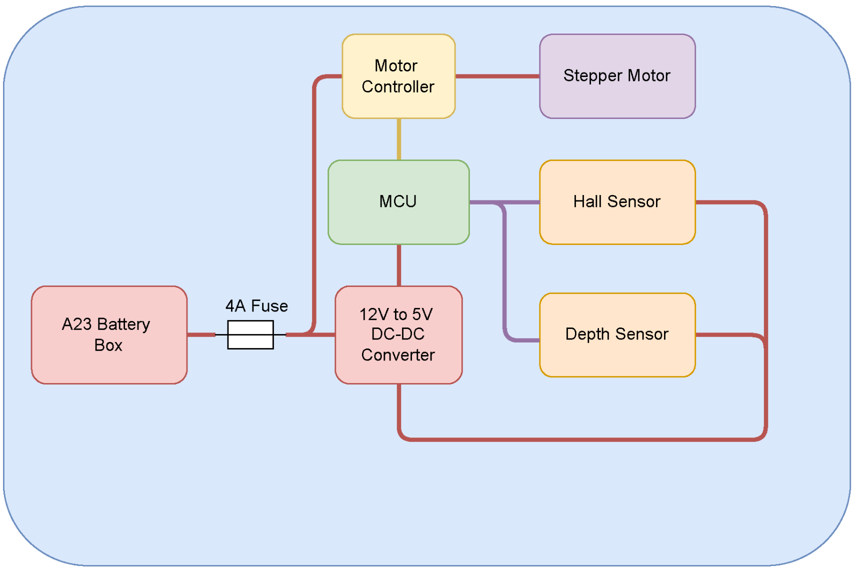
A. System Interconnection Diagram (SID) - Electrical



b. System Interconnection Diagram (SID) - pneumatic



c. System Interconnection Diagram (SID) - Buoyancy Engine



Fuse Calculation

Stepper Motor = 2.0A

Depth Sensor = 0.1A

Hall Sensor = 0.1A

Max. Current: 2.2 x 150% ~ 3.3A

Fuse Selection: 4.0A

D. Safety Operation Checklist

Operation Safety Checklist

Start-up Procedure		In Water	
Safety goggles are worn for every crew	☐	Tether man is attentively placing the ROV in water.	☐
All crew members are not dangerously near to the ROV	☐	Checked for bubbles that could mean any leakage.	☐
Ensured Main switches and circuit breaker on Surface Control Unit are off.	☐	Checked for all motors and servomotors functionality	☐
Checked that tether is connected to and from ROV is secure and non-damage	☐	If a burned out smell is detected, reel ROV back to surface as soon as possible	☐
Double checked that bolts are secure in position	☐	Everything is OK, begin mission	☐
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		ROV Retrieval	
Ensured that all member are away from the water	☐	Called "Prepare for surfacing"	☐
Informed everybody on deck before power is on.	☐	Ensured that crew members are ready for retrieval of ROV	☐
Ensured that all members are attentive and prepared	☐	Ensured the ROV is somewhere near to the crew	☐
Power source is switched on and connected to Surface Control Unit.	☐	Killed power after confirmation of retrieval	☐
Verified that the voltmeter reading is 48 volts on the LCD	☐	Ensured no power leak, called out "safe to remove ROV"	☐
Warned everybody on deck for thruster test	☐	"ROV secured on deck" is called out after ROV is secured	☐
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		Loss of Communication / Unresponsive	
Hands are removed from the ROV control panel	☐	Checked if all connections are secure	☐
Called "Prepare to launch"	☐	Rebooted the communication system	☐
Ensured all deck members are ready	☐	If failed: pull out and plug all wires again	☐
Called "Launch"	☐	Troubleshoot succeed: mission continues as usual	☐
Ensured ROV is completely submerged to water	☐	Troubleshoot failed: Kill power	☐
Wait for release	☐	Retrieved ROV via tether	☐