

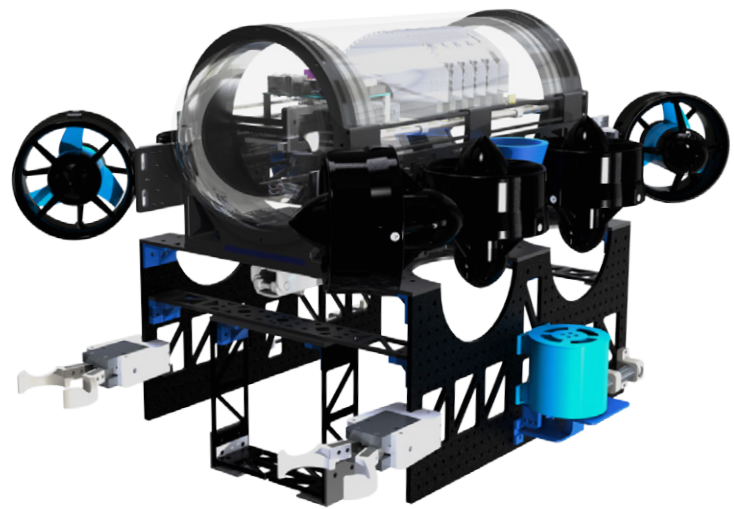
# CITYUHK

CITYU UNDERWATER ROBOTICS

# FRONTIER

ROV

## 2019 MATE ROV TECHNICAL REPORT



### Members

Sze Tsz Ho | CEO / Pilot | Year 4  
Wong Wui Leung | Project Manager | Year 4  
Chung Wing Lam | Mechanical Lead | Year 4  
Cheng Yuk Shing | Electronic Lead | Year 3  
Li Shing Hin | Software Lead | Year 4  
Chan Yu Hin | Mechanical Engineer | Year 1  
Tang Ho Tung | Mechanical Engineer | Year 3  
Yeung On Lik | Mechanical Engineer | Year 3  
Cheng Ki Fung | Electronic Engineer | Year 1  
Lam Cheuk Yiu | Electronic Engineer | Year 2

### Supervisors

Dr. Cheung, Ray C. C.  
Dr. Chirarattananon, Pakpong  
Dr. Shen, Yanjing  
Dr. Wu, Angus K. M

Lam Nga Wai | Electronic Engineer | Year 2  
Ngan Wai Sing | Electronic Engineer | Year 1  
Tang Chun Ki | Electronic Engineer | Year 2  
Wong Ho San | Electronic Engineer | Year 1  
Yue Man Hon | Electronic Engineer | Year 4  
Lau Lee | Software Engineer | Year 4  
Ng Man Lung | Software Engineer | Year 1  
Mok Tsz Ling | PR Officer | Year 4  
Wang Chi Hang | PR Officer | Year 4

### Mentor

Chan Peter

# ABSTRACT



Fig.1 CityU Underwater Robotics 2019

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 the Eastman to ensure public safety from the construction of the hydroelectric dam, maintain healthy waterways of South Fork of the Holston River, and preserve the heritage of a civil war era location.

CityUUR’s ROV is built with valuable experiences from previous projects. This year’s ROV, **Fronteer**, has incorporated with a highly modularized mechanical structure and an electronic system which allows the ROV to adapt to different usages and functions with ease. The team promotes in-house development of components such as 3D printing for prototypes with short production cycles and low cost. Advanced image recognition technique is applied to ROV for tasks. Multiple simulation tools, including Gazebo simulator and SolidWorks, are used for verifying the design.

A multi-functional, stylish ROV is born under the collaboration and dedication of Mechanical, Electronic and Software engineers for over 3000 hours, which the company believes *Fronteer* is the most suitable ROV to fulfill the Eastman’s Request For Proposal (RFP). The following technical documentation presents the design rationale and development process of the creation of **Fronteer**.

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# 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.

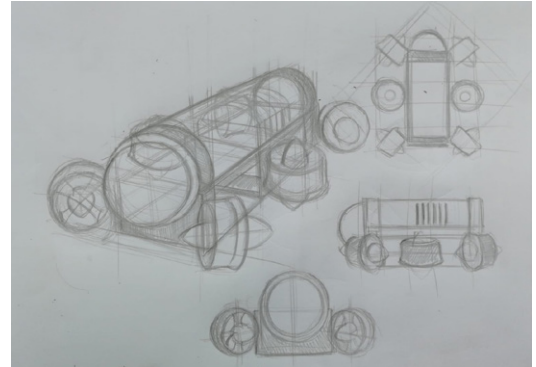


Fig.2 Hand sketch of *Fronteer* at Brainstorming Stage

### 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.

### 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.

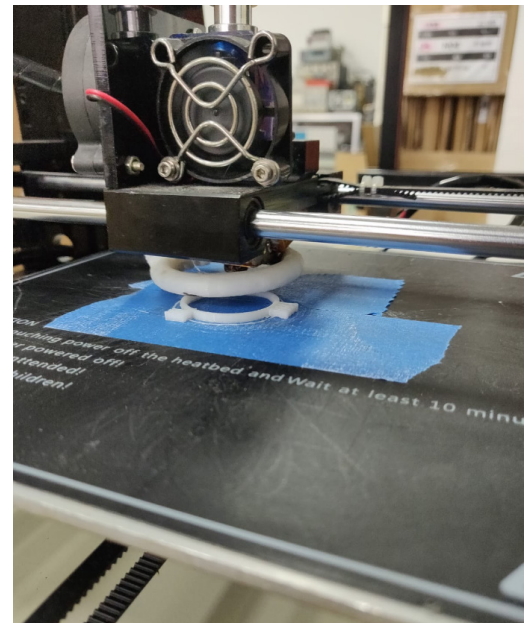


Fig.3 3D Printing Prototype of Micro ROV

### 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

As ROV is a complex vehicle that need frequent modification, this year, there was a main objectives in mind: keeping the main component and structure modular that is convenient for maintenance and reposition. Mechanical design and frame material has changed to accomodate this goal.

The frame of **Fronteer** is designed to cater different environment as it can easily switch between compact or extended frame structure for different lifting ability or component mounting space. Moreover, a electronic tube was used to provides storage and waterproof for the electronic system, rather than epoxy every single electronic component which makes later adjustment impossible.

### 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.

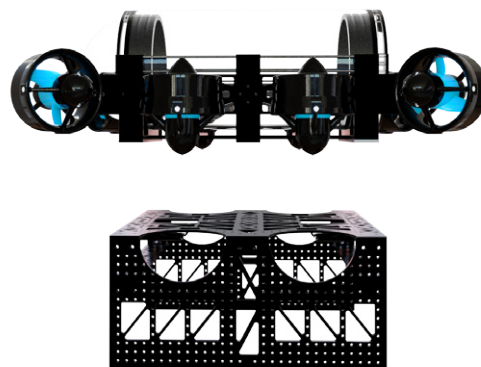


Fig.4 Exploded View of Side Frame

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.

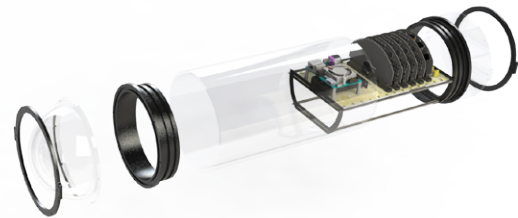


Fig.5 Exploded View of Container

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.

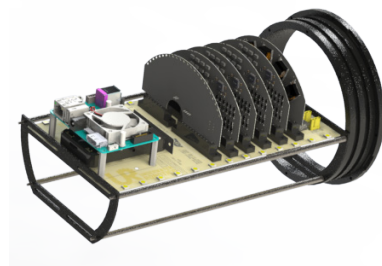


Fig.6 Electronic Housing mounted on Aluminium

### 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.

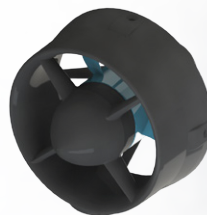


Fig.7 T200 Thruster

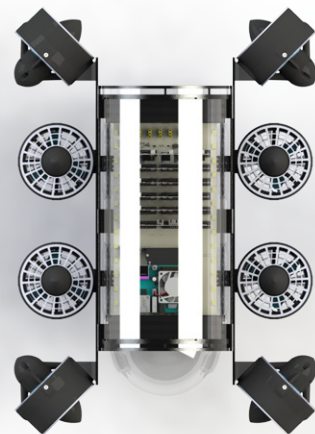


Fig.8 Thruster Configuration

### 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

One of the milestone of this year is the implementation of a modular electronic structure, by incorporating a backplane and modularizing all electronic components into daughter boards. This has huge benefit for the electronics system regarding the need for less wiring, easy maintenance and swapping of functions.

With the experience from our last generation vehicle, all controls are done with STM32 series ARM based microcontroller due to its high performance and expandability over the Atmel or PIC microcontroller.

### 2.3.2 TETHER

*Fronteer's* tether consist of two single mode optical fibers, two conductors with a pneumatic tube attached on it. Optical fiber was opted due to its high speed and high bandwidth transmission for control and vision system, providing headroom for *Fronteer's* future upgrades.

To ensure a secure retreat of vehicle under emergency, the tether itself was reinforced with Kevlar material and a steel wire connected to the vehicle and ground station at both ends as strain relief. In addition, the outer layer of the tether is made up of PU Foam, to achieve neutral buoyancy for a more stabilized propulsion, as well as reducing signal latency with optical fiber.

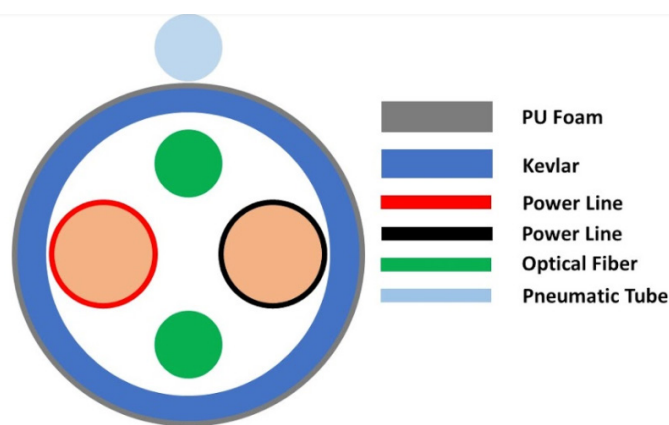


Fig.9 Tether Composition

### 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

Two telecommunication graded DC-DC buck converters are connected in series to step down 48V to 16.8V. The maximum output current of a converter is 45A current, and the maximum power could be up to 756W.

16.8V is chosen as the main power level as the efficiency of thrusters is proportional to the voltage input. In addition, other power conversion are done on the Power Daughter Board to fulfill the requirement of sub-system.

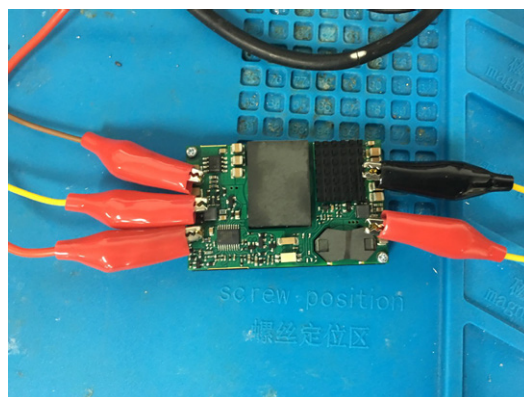


Fig.10 Testing on DC-DC Converter

## 2.3.5 BACKPLANE

In order to improve management on different sub system, a backplane is designed for **Fronteer**. It is a single PCB with the Single Board Computer (SBC) and autopilot connected. Defensively designed plugs and daughter board slots are used on the backplane, they could only be plugged in one direction, which avoid any human error during connection. To prevent overheating, a high efficiency heat dissipation design is also applied to the backplane.

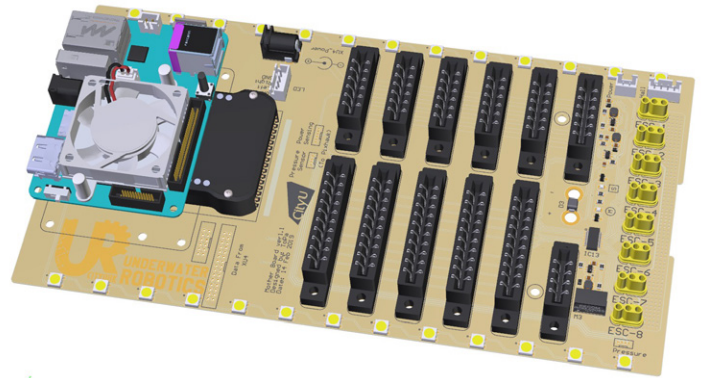


Fig.11 **Fronteer's** Backplane

The backplane are separated into three systems on three regions: Main System, Peripheral System, Power System. To avoid noise in the communication bus, placement of the system are Power system are located at the back, Main System with the SBC and Autopilot are located at the front and Peripheral System is located in the middle with all the daughter board slots.

There are a total of five daughter board slots for expansion. With the daughter board slots, 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 , SPI, UART, CAN) on the backplane. Apart from the five slots for daughter board, there is a specific slot for the power daughter board to deliver regulated power to the five power buses on the backplane.

To monitor the performance of the backplane, a Power Management Unit and Emergency Power Cut Off Unit (EPCO) are integrated in the Power System on the backplane. This is one of the safety feature of **Fronteer**, which will be discuss further at session 3.2.

## 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.

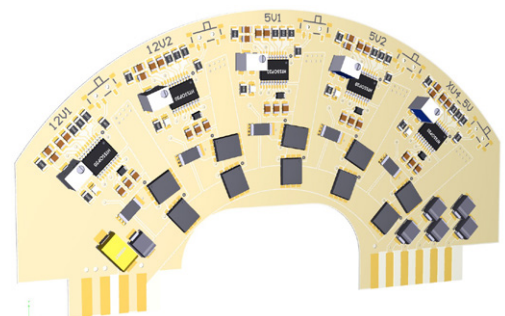


Fig.12 Rendered Power Daughter Board

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 Manipulator 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.

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.

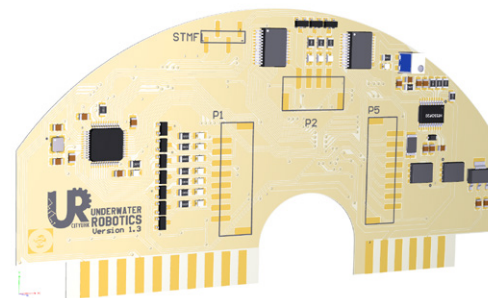


Fig.13 Rendered Manipulator Daughter Board

### 2.3.6.3 Sensor Daughter Board

Sensor Daughter Board is used to collect data from external sensors and transmit to SBC when requested. All the conversion are done onboard before transmission. DS18B20, a one wire digital thermometer is used. The temperature measurement ranges from  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  with an accuracy of  $\pm 0.5^{\circ}\text{C}$  when between  $10^{\circ}\text{C}$  to  $85^{\circ}\text{C}$ . The pH electrode used is the E-201-C glass electrode. The measuring range is between 0 to 14 pH value with an accuracy of  $\pm 0.5$  pH value.

### 2.3.6.4 Peripheral Daughter Board

Peripheral Daughter Board is the bridge between **Fronteer's** SBC and ROCam (Micro ROV). The board have embedded USB to RS485 converter to relay the communication between the SBC and ROCam. 12V power is also connected with a 6A in-line fuse to provide the required power for ROCam.

In addition, the board have a separate MCU to control external light, which provide six level of brightness for different lighting situation.

### 2.2.3.5 Camera Switch Daughter Board

Camera Switch Daughter Board is based on multiple high speed multiplexers to switch between camera to four video output lane. It allows multiple cameras installed but only require four video transmission lane to be occupied. The board is connected to the SBC, allowing Pilot to switch between cameras with one single button with the integrated design.

### 2.2.3.6 Debug Daughter Board

Debug Daughter Board is used to quickly diagnose hardware problem in the backplane. The board continuously measure the voltage of the power bus and display the measurement on a small monitor on the backplane. For the communication, the board is capable of capturing all the data on signal buses. Once a data is captured, the representing LED will be lighted up to notice the pilot. Such design could allow engineers to understand the status of the vehicle by visual indication, minimising the risk of opening the electronic tube.

Apart from visual indication, the daughter board is designed with extra test holes on the edge of the card, these hole are connected to the power buses, signal buses and thruster control buses. In case of any error, engineer can directly connect logic analyzer or oscilloscope to the test holes, speeding up the maintenance time.

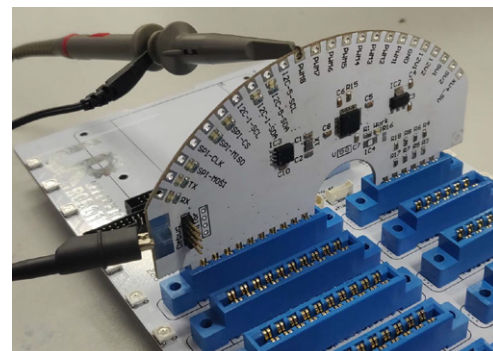


Fig.14 Oscilloscope connected to Debug Slot Card

### 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 pro-long operation.



Fig.15 ESC with heat sink

To prevent overheating and reduce risk of accidents, our engineer designed to integrate a heat-sink 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.

	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 vision for pilot to complete underwater task, nine auxiliary cameras were installed including one digital camera and eight analog cameras. Digital camera was use with computer vision software to operate the vehicle, which was installed on a gimbal at the front of the electronic tube to enable a multi-angle view for the computer. Analog camera were installed in different corner of the vehicle to provide complementary vision. As they are relatively small, they would affect *Fronteer’s* overall composition.

## 2.4 SOFTWARE

### 2.4.1 DESIGN EVOLUTION

An Odroid XU4 was used rather than RaspberryPi, which gives more computing power and allows engineers to build complex system to maximise *Fronteer’s* performance.

### 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.

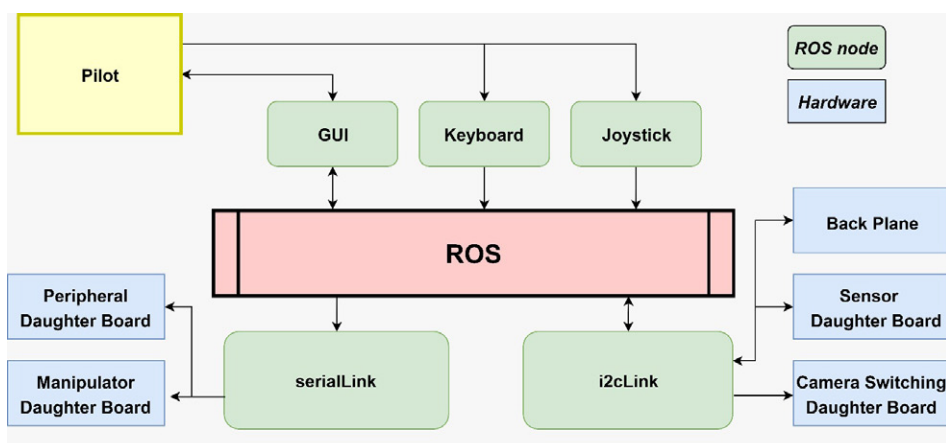


Fig.16 ROS Framework

### 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 middle-man and forms a complete channel between the GUI and the other nodes.

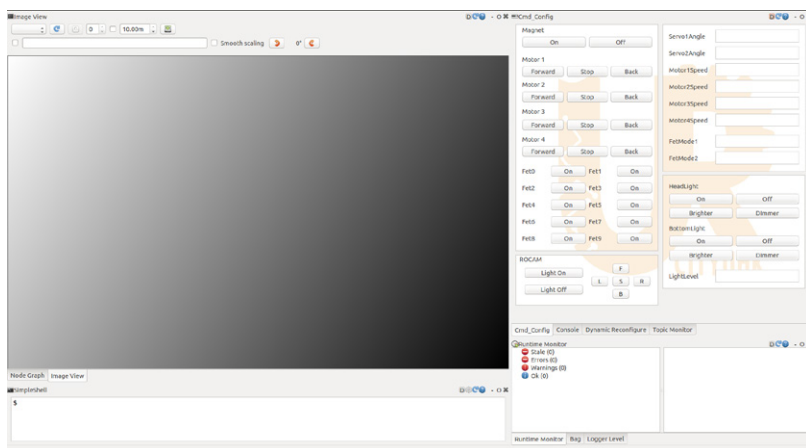


Fig.17 GUI Interface

### 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.

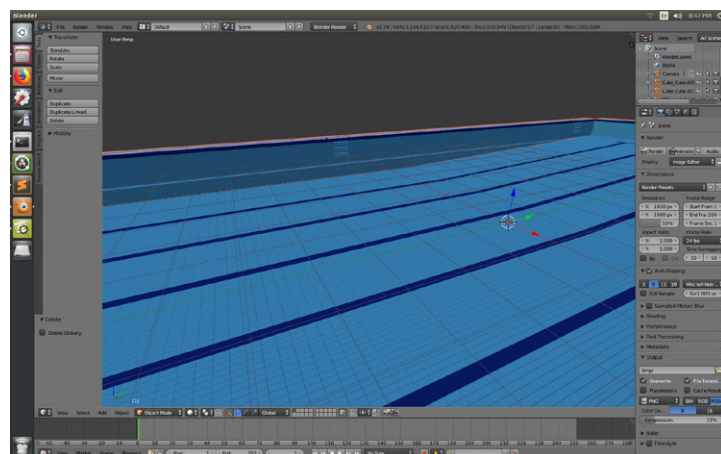


Fig.18 Virtual environment created with Blender

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.19 Control Station of **Fronteer**

## 2.6 MICRO ROV

With the harsh environment that the Micro ROV have to reach during the mission. A tiny scale ROV - Remoted Operating Cam (ROCam) is designed.

### Mechanical Design

ROCam is designed to fit in small gap and tunnel like drain pipe to perform inspections. In order to achieve such goal, our engineers minimized the overall design to keep the size down. ROCam is equipped with two thruster to provide basic maneuver.

A guide wheel system is installed on the head of the ROCam as shown in Figure 21. Combining the guide wheel and thruster, the ROCam will be able to follow the pipeline even at the tight corner. Electronics parts are stored in the head compartment which could be detached for quick maintenances.

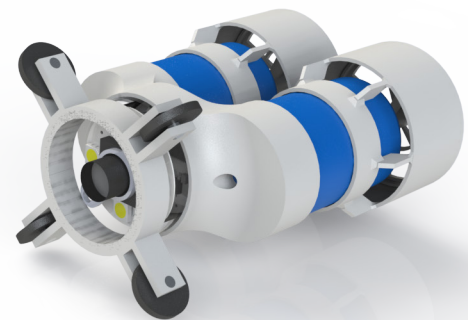


Fig.20 Rendered ROCam

### Electronic Design

Since the space inside ROCam is limited, ROCam 's electronics are divided to two layers, control board and video board, such that the size of each board can be minimize to 30mm in diameter. Both boards are interconnected with pin connector to fit in the head compartment. Microcontroller, motor driver, communication system and power convertor are embedded on the control board while the camera and LED for lighting are fitted in the video board. RS485 was chosen to be the communication protocol between **Fronteer** and ROCam because of the advantage in long distance data transfer compare to TTL.

Four 5050-LED were used as lighting during the operation inside the drain pipe. With the low light camera, ROCam would be able to deliver clear live feed to the operator.

ROCam are connected to **Fronteer** with a 5 Core Copper Tether. With this specially selected material, the tether could stay flexible and lightweight without sacrificing ROCam's maneuverability.

## 2.7 MISSION SPECIFIC TOOLS

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

### 2.7.1 MANIPULATOR

#### 2.7.1.1 Item Dropping

The cylinder container is attached with an end plate at bottom to carry pebbles and trout fry. The plate is a movable cover controlled by pneumatic force, to release object to the designated area in the pool. A guide couple is used to transfer the load from the plate to avoid misalignment along the axial axis, thus to increase safety and reduce buckling load.



Fig.21 Rendered Dropping System

#### 2.7.1.2 Gripper

The gripper is designed with curved surface and the hook-like extrusion provides resultant force which hold the rack, fish/reef ball and rock firmly. Dropping the object can be done by retracting the finger by pneumatic force combining the downward movement of the vehicle.

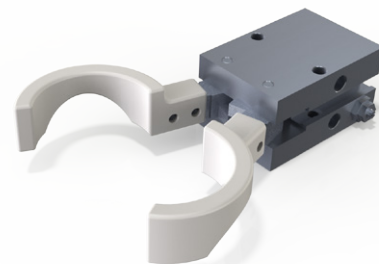


Fig.22 Rendered Gripper

#### 2.7.1.3 Cannon & Wheel Manipulator

Similar to a carabiner, the hook with hinge is used for lifting of canon. There were four L-shape hooks installed at the bottom of frame, two hooks as one group as shown in Figure 23. Since the hinge of hook provides only inner rotation, the canon can be held under the bottom of frame after its being hooked. The lift bag provided extra buoyancy for the robot to lift up the canon.



Fig.23 L-shape Manipulator

#### 2.7.1.4 Cannon Measure Device

A clipping mechanism is designed to measure the dimension of cannon. The designed end plate have a convex radial intrusion that could fit the rounded surface of the cannon, and a pneumatic actuator will push its end plate slowly approach to another side of the cannon. During this process, a camera will observe from the top side to the ruler which has been configured so that the zero is set parallel to the lowest point of the radial intrusion of the end plate.

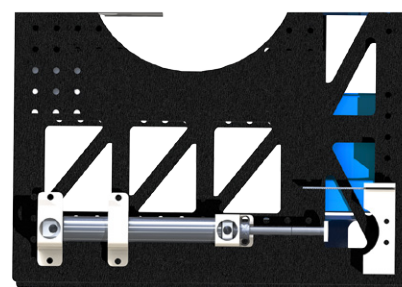


Fig.24 Measurement Device

### 2.7.2 LIFTBAG

As the total thrust for lifting cannon is smaller than the weight of cannon, two lift bags were used to provide extra buoyancy to assist the vehicle to retreat back to water surface with the cannon. The lift bag is folded and stored inside a funnel-shape container, mounted on the side of the frame vertically.

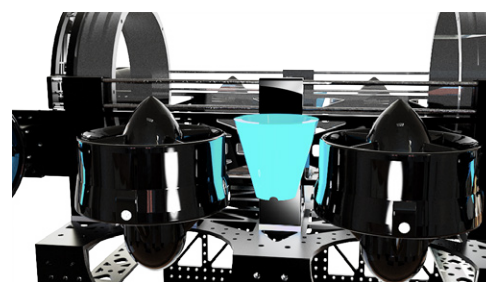


Fig.25 Funnel Shape Container

The shape promotes expansion and upward movement when cannon is lifted and liftbag is filled with air.

### 2.7.3 MICRO ROV

ROCam will be deployed near the drain pipe to replace **Fronteer** to inspect drain pipe. The pilot is able to control ROCam inside the drain pipe with the help of guide wheel. Considering the lighting environment inside the drain pipe, the pilot can control the onboard LED to light up the environment. The camera video of ROCam will transfer to the control station, where the pilot will be able to inspect possible dam failure by video image.

After the operation, the wire wrapping system constructed by PVC pipe on **Fronteer** will collect the tether of ROCam and ROCam itself, it uses two rotated wheel to direct the wire into the wire container. With the shift of rotational direction, the wire could be retrieved or released smoothly, then dock on a electromagnetic on **Fronteer**.

### 2.7.4 SENSORS

**Fronteer** has installed temperature and pH sensor to monitor water quality and collect data on temperature and pH level.

To allow the pH sensor to measure water sample inside a bucket, the mounting of the sensor is designed to rotate easily with pneumatic actuator. The inclined pneumatic actuator is mounted on the frame where one end is connected to the coupling and the other end is fixed onto the mounting of pH sensor. As part of the mounting is fixed on the frame, the actuation triggers the rotation of mounting for 90 degree, allowing the pH sensor to penetrate into the sample hole together with the downward movement of vehicle. Similarly, retreating of pH sensor is done by the retraction of actuator.

### 2.7.5 METAL DETECTOR

Metal detector placed at the front of the vehicle to identify which object is/are cannon shield(s). The sensitivity can be adjusted such that the detector can better sense the metal under the water. Once a cannon shield is detected, a message will be displayed on the GUI and a marker that held by gripper will be dropped onto designated area.

### 2.7.6 STEREO CAMERA

**Fronteer** is equipped with a ZED Stereo Camera for measuring the dimension of the cannon. Stereo images are captured, relative distances of the objects from us and the depth information between the objects.



Fig.26 ZED Stereo Camera

Since the information of the stereo camera such as distance between the two cameras and focal length is known, disparity of two images can be calculated. From these data, the depth of all points in the image can be derived to measure the length and radius of the cannon.

### 2.7.7 COMPUTER VISION

Designed with the purpose of ensuring public safety, **Fronteer** is loaded with software with the ability of inspect infrastructure and benthic species through the camera lens.

#### 2.7.6.1 Dam Inspection

**Fronteer** is required to inspect the dam and gather information on the crack such as size, length and location.

Color detection of both RGB and HSV color space will be used to detect the colored line crack while avoiding black color of the grid. Multiple Region of Interest (ROI) of V shape will be used to determine the desired direction and turning points and also prevent the vehicle from derailing from the line to enable the vehicle to follow the line.

The crack will be treated as trapezoid instead of rectangle, crack size can be calculated by using the given width range and estimated with the the pixel numbers occupied to compare to the corresponding ratio to the width.

By tracking the line of the grid and setting a ROI to determine the passing of the line, the number of grids that the vehicle has passed can be counted. By combining the recorded direction detected from the line following program, the position of Fronteer shall be mapped.

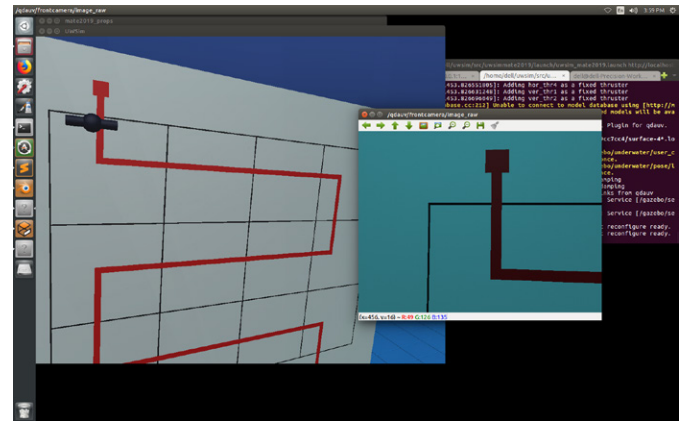


Fig.27 Line recognition simulation using UWSim

### 2.7.6.2 Benthic Species Recognition

Using functions provided in the OpenCV library in addition to our tunings, the **Fronteer** is able to separate the benthic species from the surroundings by applying color space filters and value intensity thresholding.

In addition, by integrating the methods of contour approximation and corner detection, the targets can be quickly recognized and marked into groups according to their features, in this case the shapes of the contours and the number of distinct corners. Moreover, noise reduction algorithms and camera rectification has also been applied to increase the accuracy of detection.

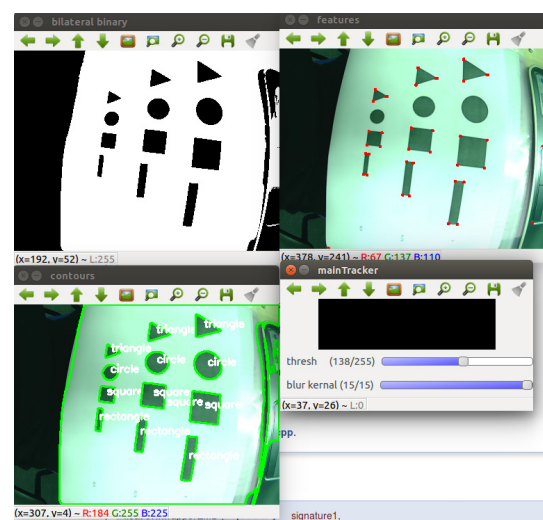


Fig.28 Fronteer identifying species

## 2.7.7 MISSION PLANNER

This year, the company has developed a desktop application, Mission Planner, to keep track on the task completion during mission run. Users can create and edit the specifics of a mission: tasks to complete, respective priority of a task, and the estimated time for completing a task.

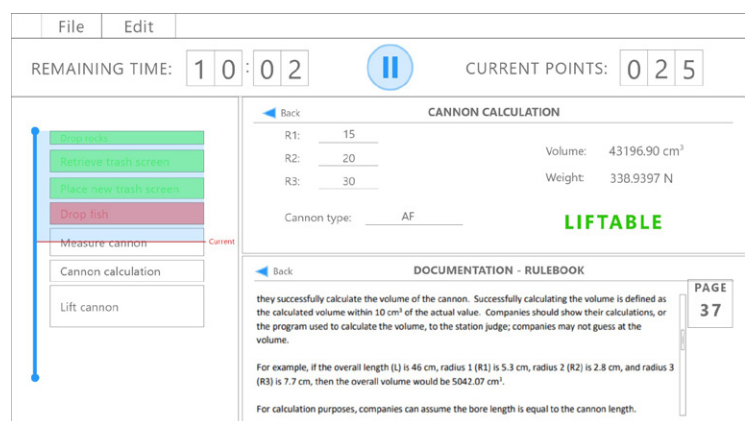


Fig.29 Mission Planner Interface

It is designed with flexibility and user-experience in mind. User can import their own programs that perform specific functions during the mission run, for example real-time calculation and conversion on gathered data. Mission-related documents can also be displayed in a separate window, allowing the crew member to know the exact rules restricting the team actions during a mission.

This application would facilitate the planning, practicing and in-field mission performance by effectively listing out all critical elements that the company should pay attention to.

## 3

## SAFETY

## 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 over-current, 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.

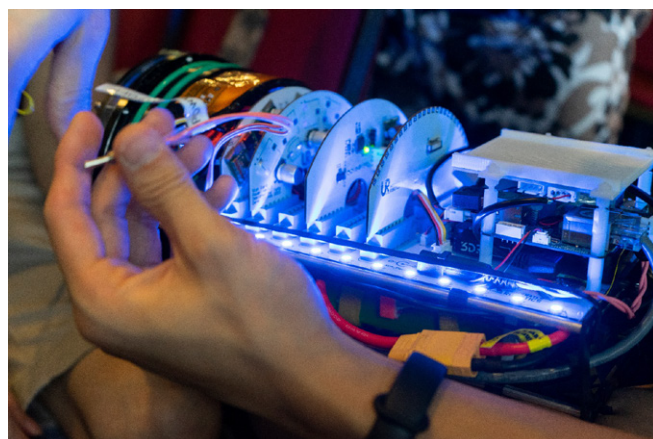


Fig.30 Backplane with Fail safe system and LED Display



### 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.

Month	Oct-18				Nov-18				Dec-18				Jan-19				Feb-19				Mar-19				Apr-19				May-19				Jun-19						
Week	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Training Workshop																																							
Boot Camp																																							
ROV Workshop for Local School																																							
Idea Brainstorm																																							
Design Process																																							
Development of Prototype																																							
Testing and Modification																																							
Final Assembly and Testing																																							
Report and Poster Writing																																							
Regional Competition																																							
International Competition																																							

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.

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.

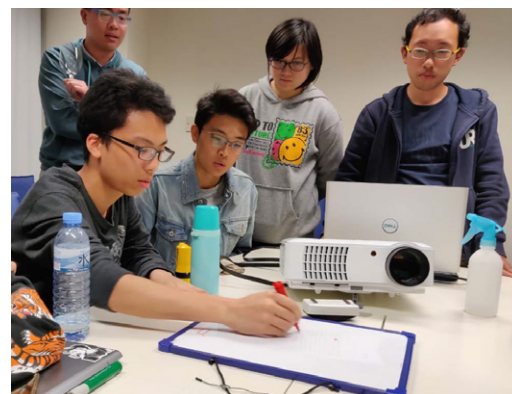


Fig.32 Idea brainstorming during weekly meeting

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.

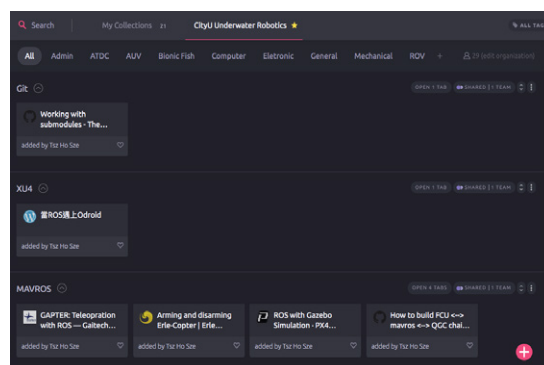


Fig.33 Toby for learning

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 2019 ROV							
Budget Category	Item/Expense	Type	Amount	Total Amount	Budget Allocated		
Mechanical	Structure	Aluminium Frame	Purchased	\$314.00			
		Waterproof Compartment	Purchased	\$150.00			
		3D Print Filament	Purchased	\$13.00			
	Pneumatic System	Pneumatic Valve	Reused	\$129.90			
		Pneumatic Cylinder	Reused	\$33.60			
		Pneumatic Tubing	Reused	\$12.40			
	Others	Epoxy	Purchased	\$23.00			
		Hardware Miscellaneous (Screws)	Purchased	\$31.80			
		Polyurethane Foam	Purchased	\$9.90	\$707.70	\$750.00	
	Electronics	Components	48V to 12V Regulator	Reused	\$49.90		
48V to 5V Regulator			Reused	\$5.00			
Anderson Plug			Purchased	\$5.40			
Fuse			Purchased	\$1.20			
Cores System		Auto Pilot	Reused	\$37.90			
		Odroid XU4	Purchased	\$28.50			
Propulsion System		Video & Internet Tranceiver	Reused	\$29.90			
		ESC	Purchased	\$17.50			
		T200 Thruster	Reused	\$1,291.00			
Vision System		Analog Camera	Reused	\$25.40			
		LED	Purchased	\$3.00			
Peripheral & Sensor		ZED Stereo Camera	Purchased	\$76.40			
		Electromagnet	Purchased	\$2.40			
		Geared Motor	Purchased	\$3.80			
		Motor Drive	Purchased	\$0.80			
		pH Sensor	Purchased	\$22.30			
Others		Temperature Sensor	Purchased	\$2.00			
		Miscellaneous	Purchased	\$38.20			
		PCB	Purchased	\$39.50			
		Waterproof Connector	Purchased	\$23.60			
Software		Control System	Wire	Purchased	\$3.80	\$1,707.50	\$1,700.00
			Xbox360 Controller	Reused	\$25.30		
	Video & Internet Tranceiver		Reused	\$29.90			
	USB Capture Card	Reused	\$9.90	\$65.10	\$75.00		
<b>Total Amount for ROV Construction</b>				<b>\$2,480.30</b>	<b>\$2,525.00</b>		
Competition Expense	MATE Registration Fee & Fluid Power Quiz	Purchased	\$764.60				
	Mission Props	Purchased	\$53.20				
	Airfare (for 10 employee)	Purchased	\$12,136.66				
	Hotel (7 nights 6 days)	Purchased	\$5,547.99				
	Team Transport Expense	Purchased	\$500.00				
	Poster Printing	Purchased	\$25.40	\$19,027.85	\$19,000.00		
<b>Total Amount for MATE Travel Expense</b>				<b>\$19,027.85</b>	<b>\$19,000.00</b>		
Operational Expense	Equipment	Purchased	\$278.00				
	Team Apparel	Purchased	\$145.00				
	Pool Renting	Purchased	\$637.01				
	Promotion Material (Poster, Flag)	Purchased	\$30.20				
	Miscellaneous	Purchased	\$9.00	\$1,099.21	\$1,050.00		
<b>Total Amount for Operational Expense</b>				<b>\$1,099.21</b>	<b>\$1,050.00</b>		
Income	College of Engineering, CityUHK	Cash	\$3,822.00				
	Department of Mechanical Engineering, CityUHK	Cash	\$9,100.00				
	Student Development Services, CityUHK	Cash	\$5,090.00				
	University Grants Committee (UGC) of HK, Funding Scheme for Teaching and Learning (Project No. CityU6/T&L/16-19).	Cash	\$866.37				
	Member Dues	Cash	\$700.00				
	Alumni Donation	Cash	\$700.00				
	Carry-Over	Cash	\$2,548.10	\$22,826.47	\$22,575.00		
	<b>Total Cash Income for 18/19</b>				<b>\$22,826.47</b>	<b>\$22,575.00</b>	
Donation	Nil				N/A		
<b>Total Raised (USD)</b>				<b>\$22,826.47</b>			
<b>Total Spent (USD)</b>				<b>(\$22,607.36)</b>			
<b>Net Balance (USD)</b>				<b>\$219.11</b>			
<b>Next Year Investment (USD)</b>				<b>\$219.11</b>			

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.

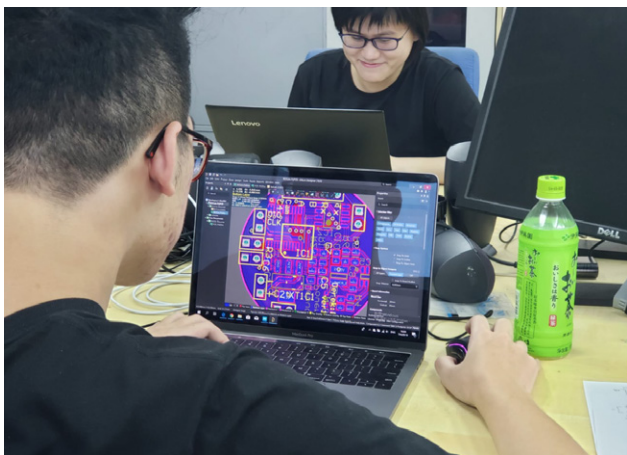


Fig.35 Electronic Engineer drawing PCB

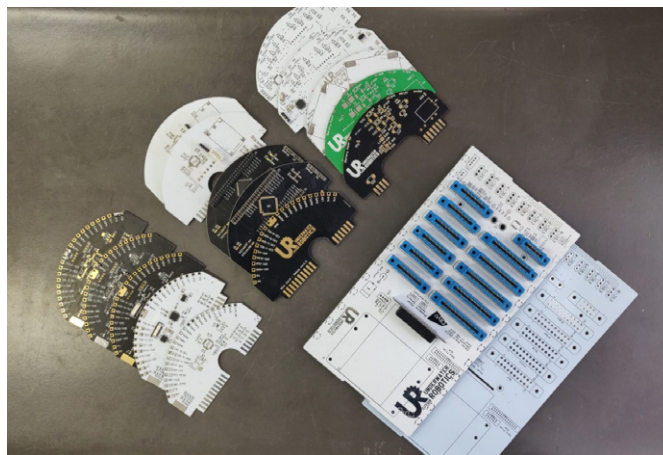


Fig.35 Iteration of PCB

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.

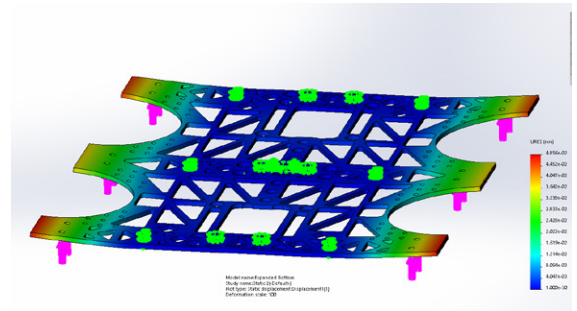


Fig.37 Stress Test on Side Frame

### Interpersonal Lesson Learned

Each year, new engineers are recruited into the company as Juneeer 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.

# ACKNOWLEDGEMENT

# 6

CityUUR would like to express their appreciation to:

**MATE Center** - For organizing the MATE International ROV Competition 2019  
**The Institution of Engineering and Technology, Hong Kong** - For organizing HK Regional of MATE International ROV Competition 2019  
**CityUHK Apps Lab** - For giving the team a lab space to work  
**CityUHK College of Engineering** - Their funding to the team  
**CityUHK Department of Electronic Engineering** - For lending optical splicer to our team  
**CityUHK Department of Mechanical Engineering** - Their support to the team  
**CityUHK Student Development Services** - Their funding to the team  
**University Grants Committee (UGC) of Hong Kong, under the Funding Scheme for Teaching and Learning (Project No. CityU6/T&L/16-19)** - Their funding to the team  
**Dr. Ray, Dr. Pakpong, Dr. Shen, Dr. Wu** - Our supervisors, for their guidance and genuine advice to the team  
**Henry, Jill, Ken** - For their support and generous donation  
**Peter** - Our mentors, for their motivation and experience to all members



College of Engineering



College of Engineering  
Department of Mechanical Engineering



Student Development Services  
香港城市大學  
City University of Hong Kong

Fig.38 Acknowledgements

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# 7

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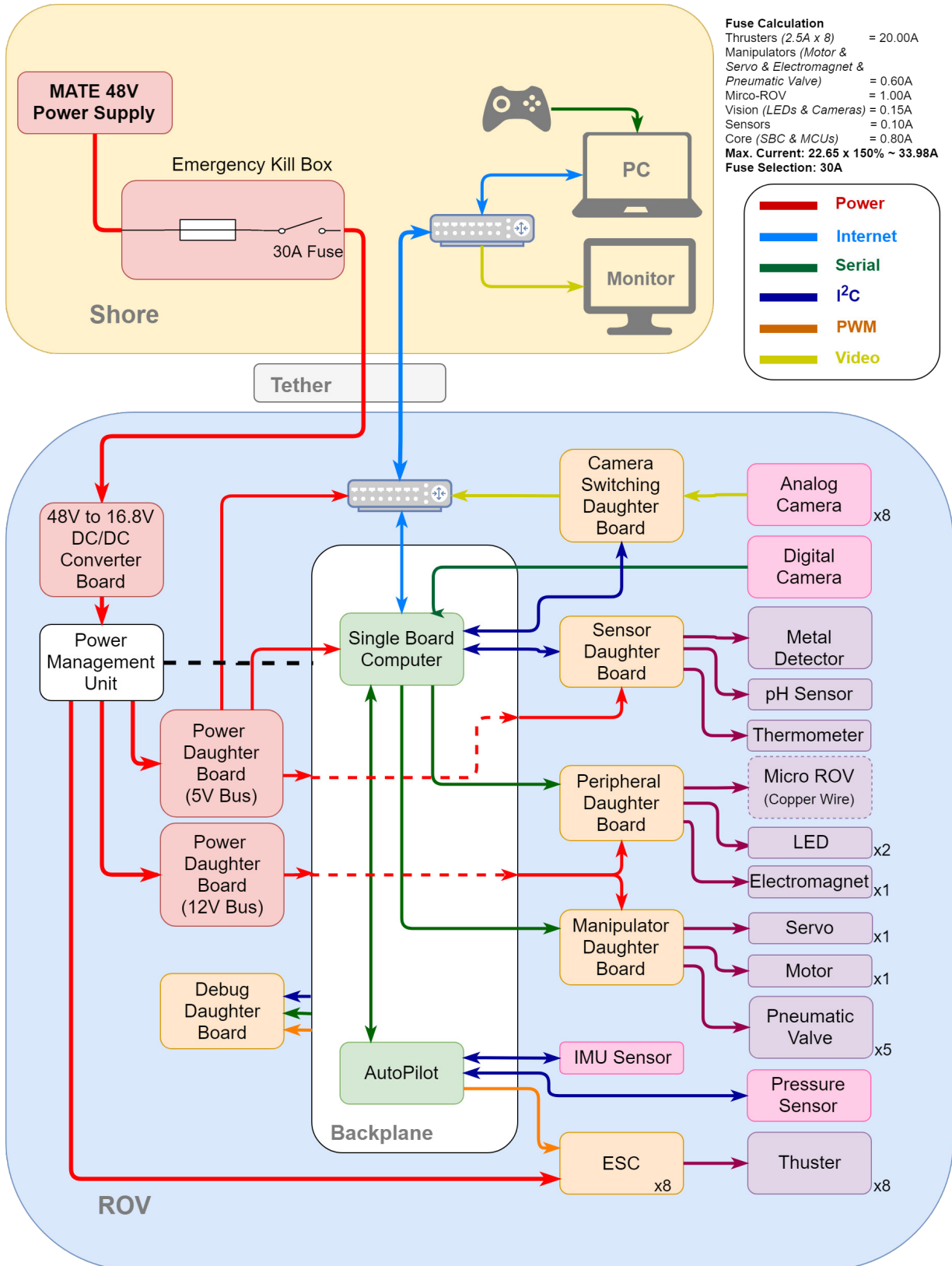
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**Maxim Integrated. DS18B20**  
<https://datasheets.maximintegrated.com/en/ds/DS18B20.pdf>

# 8

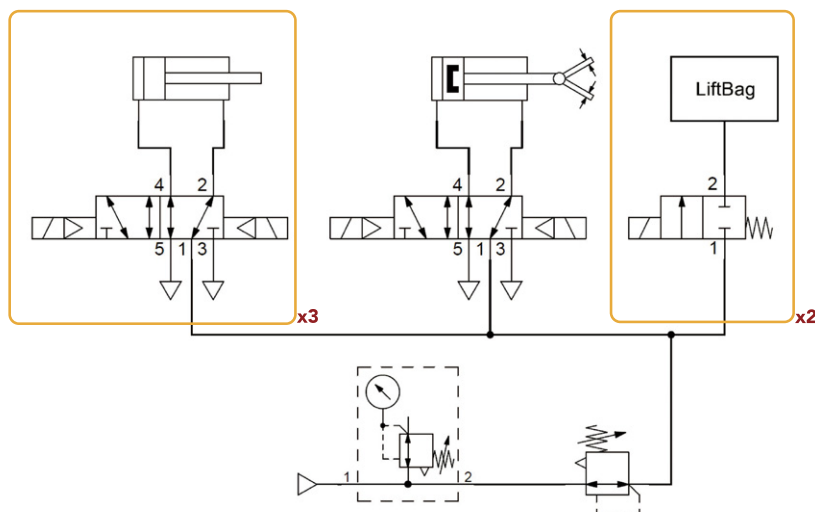
# APPENDIX

## A. SYSTEM INTERCONNECTION DIAGRAM (SID) - ELECTRICAL

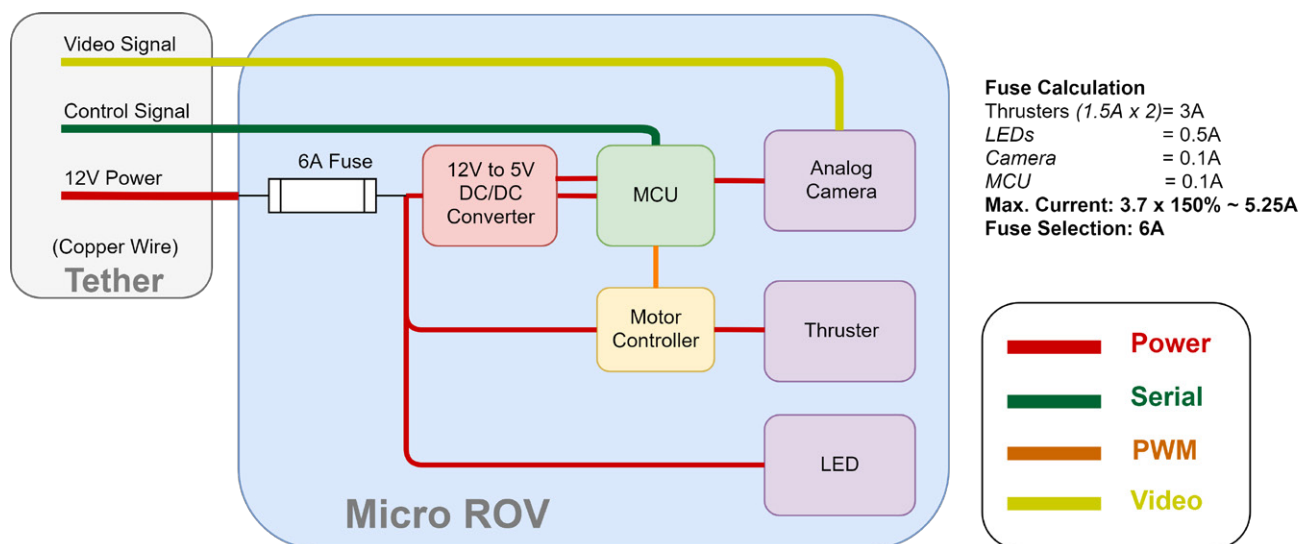




## B. SYSTEM INTERCONNECTION DIAGRAM (SID) - PNEUMATIC



## C. SYSTEM INTERCONNECTION DIAGRAM (SID) - MICRO-ROV



## D. SAFETY OPERATION CHECKLIST

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