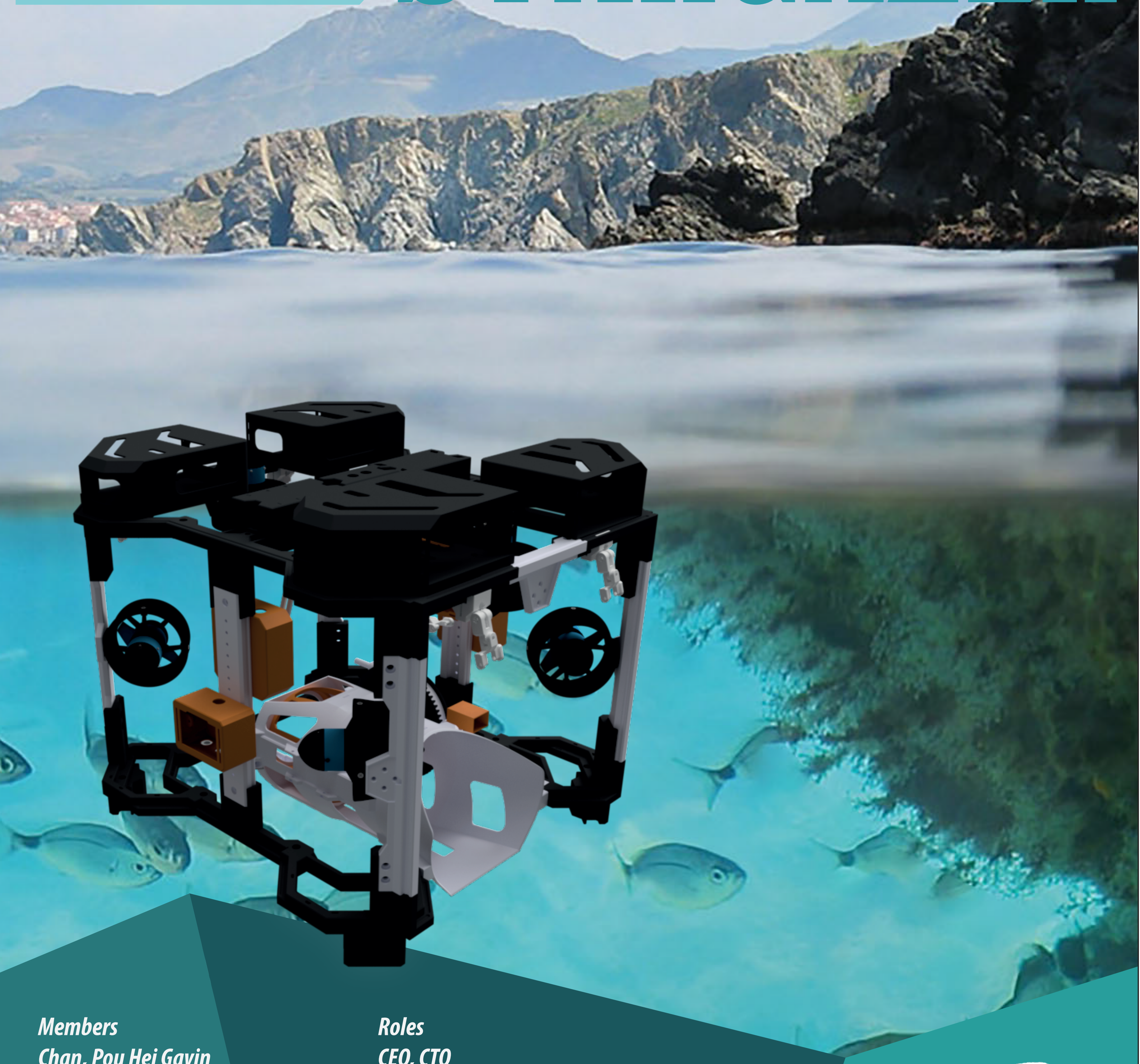
ELECTROSTARGAZER



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Abstract

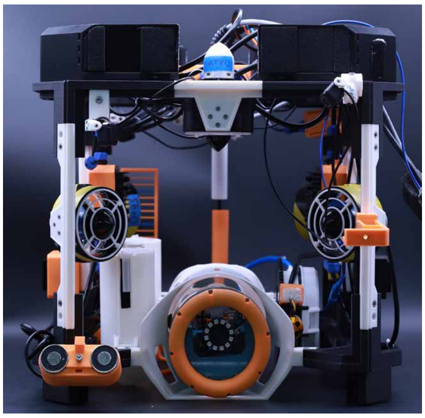


Figure 1. Complete Electro Stargazer

Electro Stargazer (ES) is Fish Logic's fourth Remotely Operated Vehicle (ROV), designed on the request for proposals by MATE Center and the Eastman Company, for an ROV for remediation of disturbed underwater habitats and installation of instruments in freshwater environments. To meet the desired functionalities, Fish Logic, a company dedicated to developing underwater ROVs, has designed ES with a flexible configuration. ES is capable of inspecting and making repairs to a hydroelectric dam, monitoring water quality, determining habitat diversity, restoring fish habitat, recovering a Civil War era cannon and also marking the location of unexploded cannon shells.

ES is fully designed by the twelve dedicated members of Fish Logic. The design is a revolution of the previous ROVs' (Leviathan and Blazin' Hydra) with the emphasis on prioritizing ease of control for the pilot, followed by ease of maintenance, ease of manufacture and ease of design.

The majority of ES's structure is 3D printed, allowing the structure to take on a very unconventional form that is modular and standardized. The structure supports six brushless thrusters and manipulators which can be "hot swapped". ES was designed to meet strict size and weight restrictions. The resulting ROV design has a flexible configuration, a small profile, with its reliability optimized through simplicity.

The development period of the ES encompasses an entire year with about two thousand work hours. The market materials value of the ES is 25,490HKD.

Design Rationale

Design Philosophy

Fish Logic has always understood the importance of having a clear understanding of the design philosophy, as it is necessary for coordinating and evaluating the design of the ROV. With the basis of equal assurance of functionality and safety, the main priority is focused on the ease of control for the pilot, followed by ease of maintenance, ease of manufacture and ease of design in their respective order of priority.

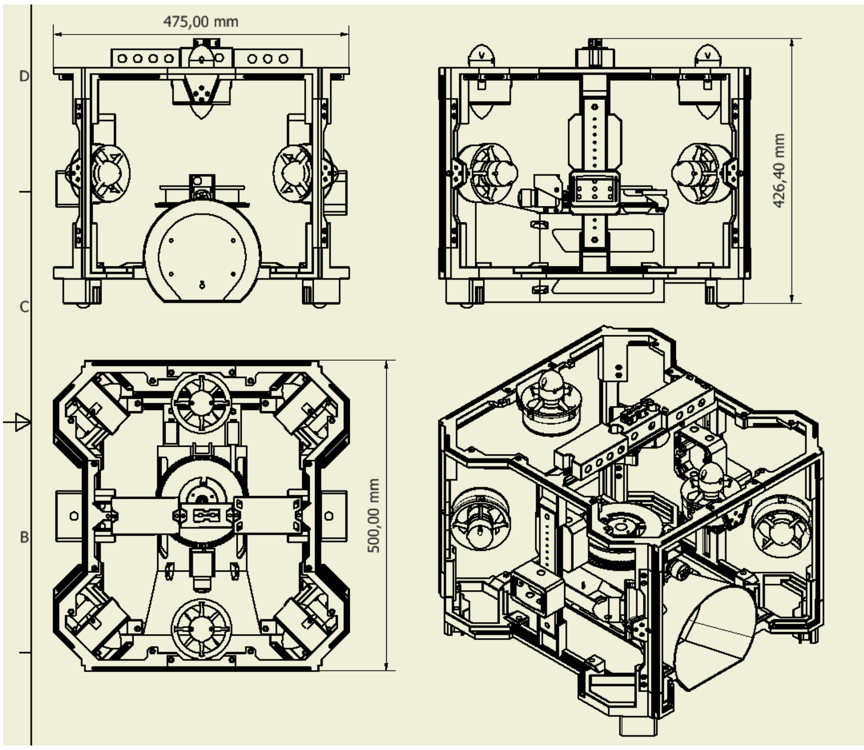


Figure 2. Blueprint of Electro Stargazer

Through reviewing our past years, Fish Logic concluded that the biggest improvement can be found by having a pilot oriented design, as it increases the speed and accuracy with which the pilot completes the tasks. The first step is to achieve optimal placement of manipulators and cameras with the rest of the ROV designed around them. The next step is stability, which is achieved through buoyancy and thruster configuration, allowing the pilot to predictably control the ROV. Agility is increased by using 6 thrusters instead of 4 on the Blazin Hydra. Furthermore, the pilot can switch the driving direction from front to rear, essentially doubling the capability of the ROV by allowing manipulators to be utilized on both sides.

Ease of maintenance is enabled through the use of modular and standardized parts. Electronic components are cast in epoxy to waterproof them reliably. Electrical standardization is achieved with the Universal connectors and I2C. I2C is a bus network which means that modules can be connected from anywhere in the network, allowing the ROV to have a flexible and scalable configuration. Interdependent electronics are housed in the same module to minimize the interface between modules to simply maintenance. Mechanical parts are standardized by the Standard Mounting System (SMS3), allowing any tools and payload with SMS to be interchangeable. This allows a generic ROV to first be developed, then specialized later when mission details are released. For reliability, simpler design options are considered first, therefore passive tools are prefered to reduce the chances of component failure.

Ease of manufacturing is accomplished through the extensive use of 3D printing, which guarantees that all the manufactured parts are of consistent quality and frees up team members to focus on the design of the parts while the parts are fabricated.

Lastly, ease of design is achieved through standardisation as it allows the configuration to be flexible. The front-rear and left-right symmetry reduces the parts needed to be designed. 3D printing, compared to subtractive manufacturing, also reduces the geometric constraints when designing components.

Mechanical

Material Choice

The extensive use of 3D printing defines the selection for the material choice, as 3D printing allows for designs to have less restrictions from subtractive manufacturing processes such as CNC milling and produces less waste. Additive manufacturing allows us to create prototypes rapidly, therefore boosting workflow and allowing fast paced innovation. Moreover, the advantages of weight-saving, complex geometric designs from 3D printing can be exploited to maximize the functionality of each component. PLA+ from eSUN is the choice of material for all the 3D printed parts on ES, and is a blend of PLA (Polylactic Acid). ABS (Acrylonitrile Butadiene Styrene) is also a common 3D printing filament, however ABS is hard to print due to warping, and releases toxic fumes in the process. Regular PLA was also experimented with, but was found to be too brittle. PETG has great elongation properties but is too flexible and have an increased cost of 60% to PLA+. PLA+ has a higher elongation at break and is therefore less likely to crack, while still having ease of print and print quality offered by PLA. An additional benefit of using PLA+ is that, along with regular PLA, it is a biodegradable thermoplastics which has a lesser impact on the environment as they can be broken down by bacteria after it has served its purpose.

Manufacturing Techniques						
3D Printing					CNC	
Advantages: More efficient, only uses the amount of materials that make up the object that it is printing Easy to print and operate Parts produced are lightweight, ideal for ROV Disadvantages: Slower, printing layer by layer can take hours for a small part Limited material selection					Advantages: Typically faster in large-scale manufacturing Wider material choice Disadvantages: Less efficient, uses more material then needed Process is much more expensive	
Materials	**PLA**	**PLA+**	**ABS**	**XT(PETG)**	**Aluminum**	**Iron**
Density(g/cm^3)	1.24	1.24	1.04	1.30	2.70	7.874
Elongation at break (%)	5	29	22	228	12	0.52
UTS (MPa)	73	60	43	49	276	275
Ease of Manufacturing	East to print	Easy to print	Difficult to print. Warping issues, and produces toxic fume requiring a heated enclosure	Difficult to print. High heating temperature. Warping issues.	Difficult to mill. Lack of in house 3D milling machinery	Difficult to mill. Lack of in house 3D milling machinery

Table 1. Comparison of different manufacturing techniques and materials.

SMS

The Standard Mounting System 3 (SMS3) is the third generation of the quick mounting system used in most of the tool and camera mounts on ROVs. The SMS3 in ES is an improvement of the SMS2 from Blazin' Hydra. The SMS3 is designed so that manipulators can be quickly swapped and camera position can be easily changed. Compared with the SMS2 rail, the SMS3 rail has been reduced in size but increased in strength, and the need to take the screw out when changing tools is eliminated.

The SMS3 consists of a C-bracket and a rail. The C-backet of the SMS is used to clamp onto the rail and is secured by a single M5 screw and nut.

The use of one screw decreases the time needed for tightening. A nut trap integrated into the C clamp removes the need to use a wrench when securing the C-bracket. Studs are added on the C-bracket to prevent rotation when mounted, reducing movement and resulting in a stronger mounting force. The SMS rail is the counterpart to the C-bracket, allowing tools and cameras to be mounted anywhere on the rail precisely, according to the pilot's preference. The bottom front SMS rails have been measured along with the camera viewing angle to ensure that all tools mounted on the rail are within the ideal viewing distances of the main cameras. There are additional SMS rails all around the structure of the ROV to provide ample mounting spaces for the optimal and flexible placement of tools, as well as reducing the need to change tools due to lack of space.

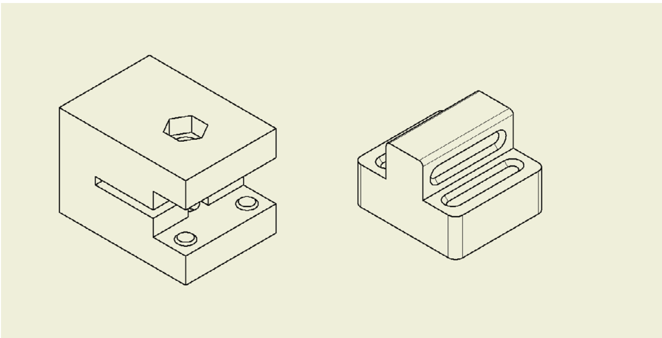


Figure 3. Blueprint of the SMS

Buoyancy

An ideal ROV should provide the pilot with stable control of the ROV. The ROV should only move in the direction the pilot wants it to, and should stay in its position until the next command. To achieve this, the average density of the whole ROV is decreased to the density of water, achieving neutral buoyancy.

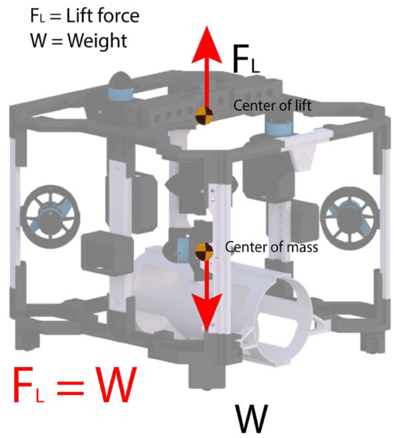


Figure 4. Center of Weight and buoyancy

Foam is used to compensate for the weight of the ROV in water. High density PU foam is selected as it can be easily cut into shape and reduced in size for adjustment while capable of withstanding increased pressure. It can also be placed anywhere in one of the four foam chambers are situated at the top of the ROV for precise adjustments in order to maintain the upright stance of the ROV when there are changes in the loads of the ROV. The sizes of the foam chamber is calculated to house enough foam to offset the weight of ES in water with additional capacity to account for the extra payloads.

25mm Stainless Steel Ballast balls (64g each) are added to the bottom of the ROV on each corner. This lowers the center of gravity of the ROV, while supporting the ROV when landing on a surface and allowing the ROV to roll on the pool bed. Having the center of gravity low and the center of lift high above helps increase the overall stability.

Propulsion

The ES utilizes 6 thrusters. Two BlueRobotics T200s mounted at the top level of the ROV for vertical and pitching movements. The other 4 BlueRobotics T100s are mounted one at each corner, each at 45 degrees to the front or rear. The lateral and longitudinal movements are provided by the resultant force of the 4 horizontal thrusters.

This 6 thruster configuration was chosen over the 4 thruster configuration used in previous years, as it provides an extra degree of movement, lateral translation. This means that the pilot does not have to approach the target facing forwards, and removes the possibility that the pilot may have to back up and re-approach the site when the ROV is misaligned.

These thrusters from BlueRobotics were chosen as they are compact while being powerful and reliable. The BlueESC that came with the thrusters, however, had many technical and reliability issues. This led to Fish Logic integrating Afro 20A ESC from HobbyKing onto the back of the thrusters, which fixes the issues, increases the power from 3N to 5N, all while keeping the same silhouette as the original BlueESC.

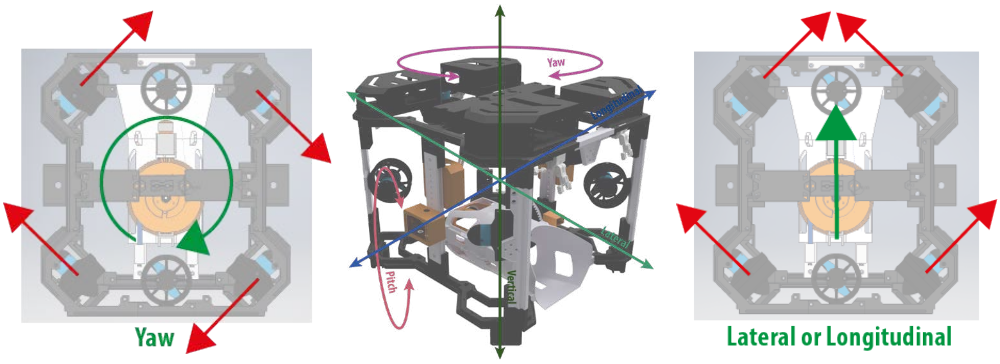


Figure 5. 5 DOF by six thruster configuration

SID

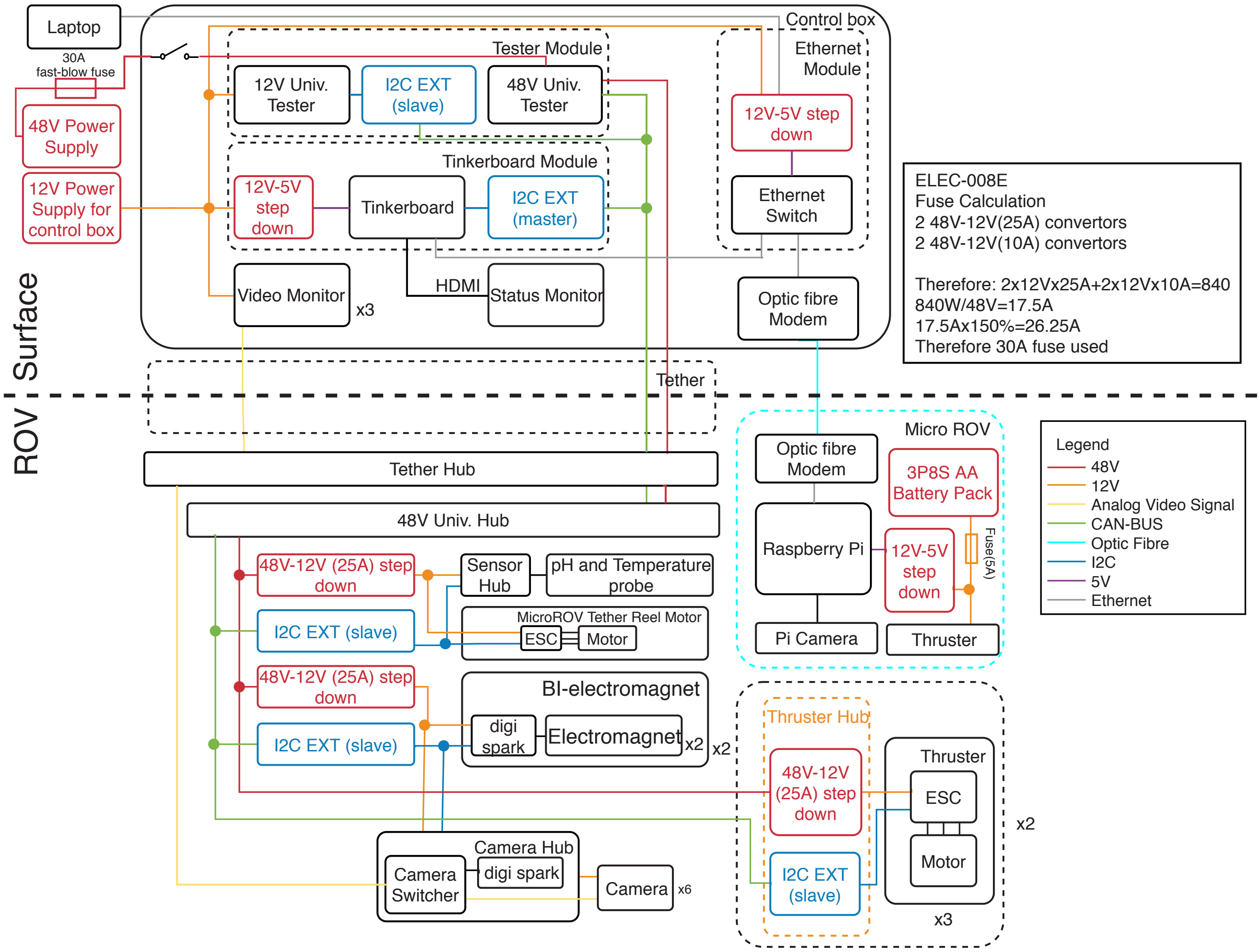


Figure 6. Sytem Integrated Diagram (SID)

Electronics

I2C Bus

An I2C BUS network is used as the main protocol in the ROV and is the key to achieve standardisation. I2C with standardised plugs allows all onboard components to be connected from anywhere on the network, making the ES's configuration flexible, and simplifies its circuitry and assembly.

Devices are connected to the I2C network directly as I2C was selected over the alternatives mainly for the ease of use and widespread support from hardware manufacturers of small electronics and the community. Controller Area Network (CAN) is another BUS network used for real-time communications, however it requires a dedicated communication chip, therefore it is only used as a transparent part in the middle of the network where devices do not need to account for its presence and function, as if they are connected to a pure I2C network.

The I2C network expands across the tether all the way to the control box which runs the control program, allowing a direct connection without an onboard translator which may add complexity. This is achieved by using off-the-shelf Sandbox Electronics I2C extenders at each I2C termination which extends the transmission range from around 4m (which is too short to cross the tether) to 300m. The extender works by first decoupling the I2C into transmit and receive, then converting it into a CAN signal. I2C is converted to CAN bus is because it has the range of more than 1400m, achieved by using differential signalling. With the number of onboard devices, the onboard network circuitry length is also too great for one I2C network to cover. Therefore, there are four onboard I2C extenders, one in each step down module to reduce the networkings for each I2C network, all connected together on one single CAN bus network.

Camera System

Figure 7. The analogue camera used on ES

ES is equipped with 6 wide angle cameras. There are 2 primary cameras providing an optimally placed forward view for both driving directions. Up to 4 secondary cameras can be mounted on any SMS rails of the ROV to provide extra viewing angles to the manipulator, this saves the pilot from having to guess the distance as a single view angle from the primary camera and allows the pilot to make accurate and precise maneuvers.

Wide angle analogue cameras are used as they offer lower latency than digital cameras and are waterproof, lightweight and compact. The digital Raspberry Pi camera in the micro-ROV is used to spot for muddy water and for computer vision as it captures high resolution footages and is natively supported by the Raspberry Pi.

Electrical

Power Distribution

The ES operates with 48V DC, giving it the benefit of allowing the use of a lighter and more flexible power tether as less current is needed to deliver the same amount of power as 12V. The four 48V-12V step-down converters that delivers 12V to the rest of the devices are separated into a group for thruster and one for the rest. This reduces the required current capacity for each module and enables the power distribution system to be more modular and decentralized as there are less devices connected to each module. In addition, the noise inducing thrusters are isolated from the sensitive cameras so as to not affect the video quality. These off-the-shelf step down converters are both integrated and waterproofed while having high current capacity.

Connectors

Universal connectors 48V & 12V

There are two types of Universal connectors, 48V and 12V. The 12V Universal connectors, identical with Blazin' Hydra's, are used to connect thrusters, manipulators and sensors to any 12V Hub since all connections are standardised. Both types of connectors deliver power and signal which greatly reduces the amount of connectors used, and reduces the probability of having issues with waterproofing and the components sizes. The 12V Universal connectors provide sufficient current throughput to the thrusters using 2 pairs of pins for power as 1 pair of pins is only rated at 5A.

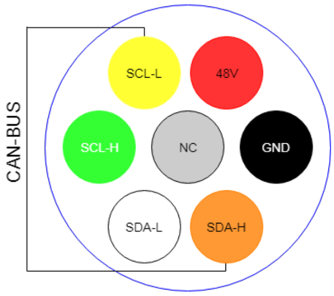


Figure 8. Universal connector pin definition

Control Box

The control box uses a modular system to manage the large amount of components in an organised and coherent manner. 3D printed modules were designed to house electronics of interdependent functions together and minimize the connection between modules. This allows for fast replacement for malfunctioning modules and gives flexibility by allowing for continuous improvement in design. The three monitors display video feeds, providing the pilot with multiple points of view while the fourth monitor displays the status of the ROV.

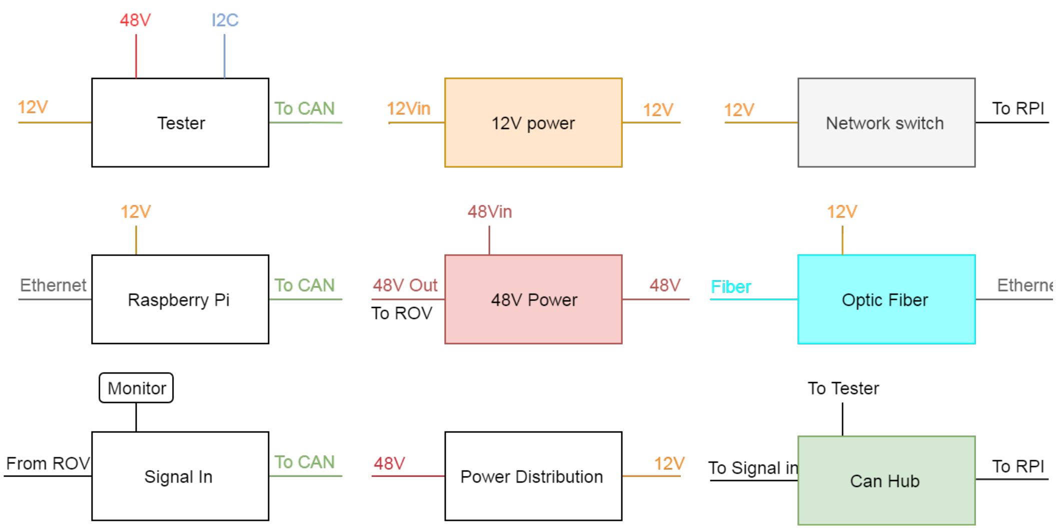


Figure 10. Modules in control box

The electronics of the control box can to be easily accessible as the electronics rack can be lifted up for maintenance. All components are clearly visible underneath the rack which speeds up inspections and troubleshooting.

Figure 9. Control box with four monitors on the top, and the module racks on the bottom.

The control box is designed with safety as the predominant factor. This control box is made with a protective splash-proof case. In case of emergency, a kill switch can cut all electricity to the ROV. The clean surface with only ports exposed when the rack is lowered, preventing accidental contact with the electric components underneath.

Software

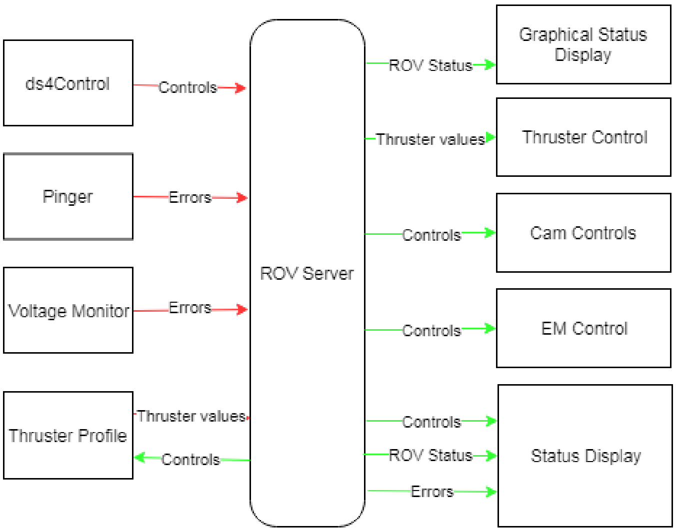


Figure 11. Control program block diagram

The ROV control program is composed of independent, loosely coupled modules. Designed in a publication-subscription pattern, modules will broadcast messages while subscribing only to interested topics. The team have implemented this pattern with the help of the socket.io library which allows the message to be broadcasted in plain text through web socket. This design has many advantages:

Firstly, it allows developers to easily swap out different modules as new modules or functions can be added to the existing system without the need to modify any original code.

Additionally, it simplifies and improves efficiency in maintaining and editing the modules. With the design structure, every layer of the structure can easily be isolated, which allows us to easily pinpoint errors.

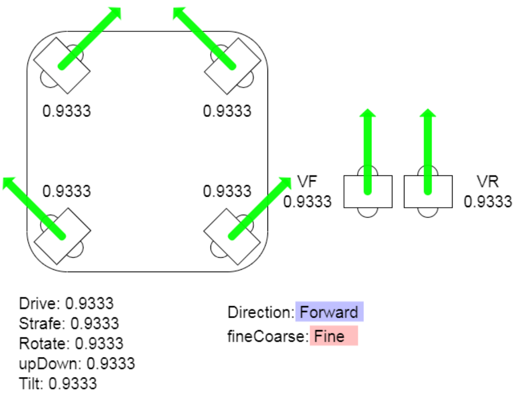


Figure 12. Graphical status display

Lastly, serving the message through websocket means that the message can be accessed remotely. The team developed a web based real-time status monitor and also allows potential remote control interface over the Internet.

Mission Specifics

Bi-Electromagnet

Two Bi-Electromagnets (BEM) are utilized for 5 specific tasks across the 3 mission sections: void filling, trash rack screen replacement, transportation of trout fry, installation of reef ball and cannon shell marker placement. BEMs are used instead of non-electrical tools as they are easier to manufacture, maintain and use, while being more reliable and versatile. Waterproofing is simple as all wiring is already insulated in the construction of the BEM solenoid circuitry and it has no moving parts.

Figure 13. Angled Bi-electromagnet with U-bolt hooked on it.

The design of the current BEM is an evolution of the BEM from Blazin' Hydra, which was designed for manipulating objects with U-Bolts. The side-by-side mounting of the electromagnets (EM) allow for a larger contact area and strength (2x18kg lifting capability) compared to a single EM, which is insufficient for holding onto the curved surface of the U-Bolt. A BEM with a 60 angled mount is used to hold the trash track for installation, with the rack already at the angle of installation, it simplifies the task as the pilot only has to navigate to the location and does not need to carefully tilt the ROV while avoiding lateral movements that may cause the rack to tilt over at the base.

Trout and Grout Dispenser

The Trout and Grout Dispenser (TGD) is designed with 2 containers, to deliver both grout and trout fry in a single run. Each container is covered by a large flap, which is supported by a smaller flap when the EM is attracted to it.

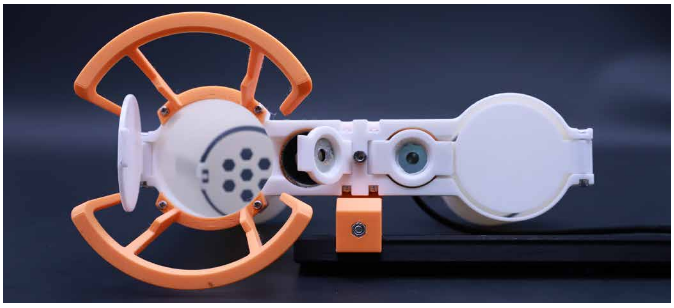


Figure 14. Grout and trout dispenser assembly

The EM has a tendency of inducing magnetism in the smaller flap, causing the secondary flap to stay attracted to the EM even when it is deactivated. A reversed polarity pulse is produced by the EM, to neutralise the attraction to the flap, thus guaranteeing the release of the flap.

A guide piece is attached to the opening of the TGD, which serves to funnel grout into the void and allow the flaps to open while the ROV is perched on top of the cup, this reduces the difficulty and precision needed from the pilot to execute this task.

Figure 15. Grout and trout dispenser with guide piece

Image Recognition

Dam inspection

The team has developed a software to locate and gather information of the crack. As the ROV inspects the dam, the software will process the video input with a colour filter to filter all colours except blue. After filtering everything that is not blue within the video, it will then look at the contours to find a contour with four sides. The sides that is shorter in length is identified as the width. The scale of the photo is then found by comparing the size of the crack width in the photo with the known actual width. The length of the crack can then be calculated with the scale and the results will be displayed.

Benthic Species

In order to identify the benthic species under the rock, OpenCV image processing library for corner and color analysis is used. Live stream video from the micro ROV is used as the video input for recognition. The color video is first converted to a gray video. Then using the cv2.findContours function, the contours are detected, and the number of sides of the contours are counted. If the contour has three sides, it will be identified as a triangle. If the contour has four sides, and its aspect ratio is greater than 0.90 and less than 1.10, then it will be identified as a square, if not then a line. If the contour has more than four sides, it will be considered as a circle. Then it will sum up the amount of each shapes detected and display the result on an output screen, with the shapes drawn in it and a number indicating the amount of each shape identified next to it.

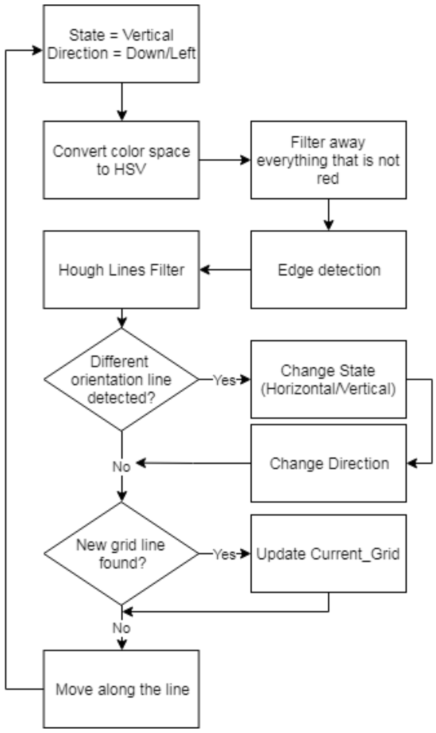


Figure 16. Flowchart of line following for dam inspection

Task 1: Ensuring Public Safety - Dam Inspection and Repair

Micro ROV - Macaron zero

Macaron zero (M-0) is the micro ROV used to enter and monitor the tunnel for muddy water, and provide video feed for computer vision tasks including recognising the benthic species and autonomous line following to determine crack length. Camera footage is sent to the surface laptop for processing.

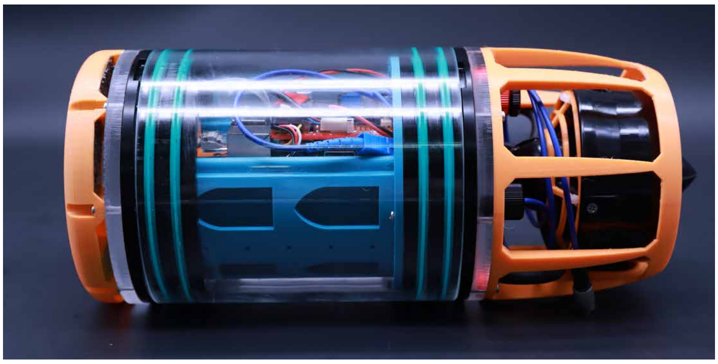


Figure 17. Mirco ROV - Macaron Zero.

The cylindrical structure of the Micro ROV is mainly constrained by the tunnel's diameter; while the length is constrained by the curvature of the tunnel. M-0 is about 130mm in diameter and 290mm in length, which is well within the maximum sizes to prevent the M-0 being stuck as it uses the walls of the tunnel to guide its movement. Being restricted by the tunnel to one-dimensional movement also enables the M-0 to be sufficiently propelled by one thruster.

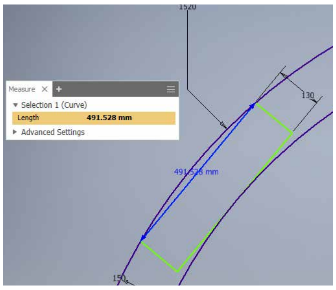


Figure 18. Maximum length of M-0 for smooth turning

Macaron Zero uses onboard battery, so it requires a canister. The batteries are placed to the bottom of the canister rim, leaving maximum inner space for the electronics and prevent rolling by having a low centre of gravity.

Load (mA)	AA battery voltage (V)
0.00	1.60
100	1.56
200	1.50
300	1.34
400	1.27
500	1.29

Table 2. Voltage drop VS current in alkaline AA batteries

The battery pack consists of 24 AA cells in a three parallel series, with eight cells in each series. This give a nominal 12V and the three parallel series can provide a 0.9A at 10.72V 1.34*8=10.72V. It is critical to have sufficient voltage under load as to prevent the thruster's peak loads from shutting down RPi by dropping the input voltage.

Having an onboard power source eliminates the need for thick power tether cables. Along with optic fibre replacing copper signal cables, this results in a lightweight and flexible tether that does not impedes the ROV's movement while occupying less space than a copper cable.

Micro ROV Silo

Since the M-0 can only travel in one direction, the micro ROV silo is required to be positioned low for deployment into the drainage pipe. A tether reel, attached to the side of the micro ROV silo, is used for the recovery of the micro ROV and safely storing the fibre optic cable. It is powered by a waterproofed brushless motor, driving the tether reel through a bevel gear. To prevent the fibre optic cable from getting tangled at the gear, a shroud is made as an enclosure for cable storage. As the fibre optic cable is secured on one end at the connecter, the winding of the tether spool will cause the cable to twist and may break the cable, thus an outer chamber is added to provide space to relief the cable.

Figure 19. Mirco ROV in the silo with the tether wheel attached on top.

Task 2: Maintaining Health Waterways

pH and Temperature Sensor

The pH probe is a silver chloride reference glass electrode with a integrated thermistor that is used to measure the pH of the liquid sample and the temperature. Before the measurements are taken, calibration of the pH probe is needed. Buffer solution of known pH value (pH 7) is prepared , the raw reading from each solution is recorded and the calibration constant is calculated. The pH value after calibrated is given by the following equation:

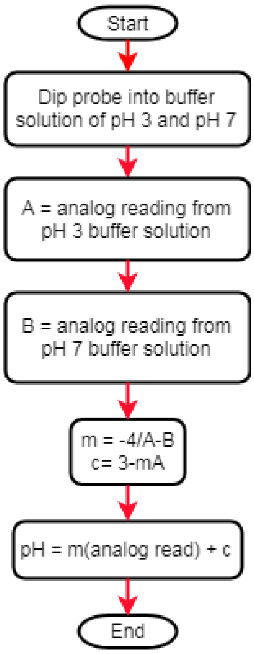


Figure 20. pH probe calibration procedure

$$
\begin{aligned}
&3 = m(A) + c \\
&7 = m(B) + c \\
&\therefore m = -\frac{4}{A-B} \quad and \quad c = 3 - m(A)
\end{aligned}
$$

The mechanism in the housing is inspired by the retractable pen where the probe can be extended deeply in the sample, ensuring the measured sample is uncontaminated by the surrounding water, and be retracted when not in use. The mechanism is initially retracted and "clicks" when penetrating the cling wrap to its extended position. After the measuring, the probe will then be "clicked" back in place by pressing against the bucket lid.

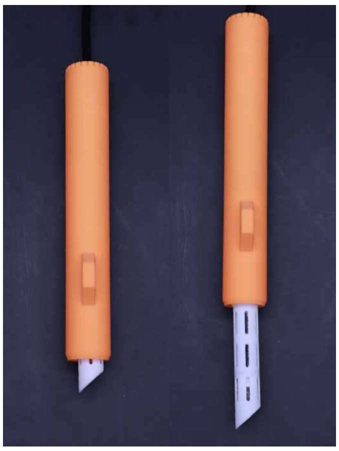


Figure 21. The pH probe retracted (left) and extended (right)

Figure 22. pH probe and its housing before assembly

Compared to holding the probe away from the ROV with an extension arm to reach the center of the bucket, this housing is far more compact and unobstructive.

As the mechanism is based on a common household item, it is reliable and worth its extra complexity. Using a syringe to draw the liquid to the ROV was also considered, however this method is far more complex than measuring it directly and also risks drawing in pool water, contaminating the drawn sample.

Rubber Tyre Hook

The horizontal U-shape tyre hook, held in place with magnets, allows the opening of the hook to face forward and slide underneath the rubber tyre. When the ROV lifts the tyre, the weight of the tyre will swing the hook down, trapping it. The tyre is held securely as the hook will swing along with the tyre's movements, preventing it from slipping out.

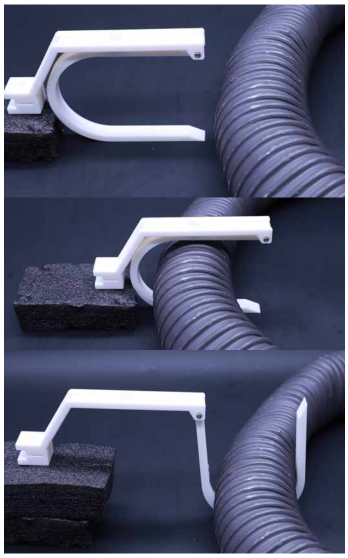


Figure 23. The tyre hook in different state.

Task 3 - Preserving History

Cannon Measurement and Retrieval

A vertical ruler is attached in front for measuring the cannon diameters. A photo of the cannon's side will then be taken and the photo scale is determined by comparing the cannon diameters in the photo with the measured cannon diameter. The scale can then be used to determine the cannon length.

A noose attached to a lift bag is used for retrieving the cannon. This allows the lift bag to be securely attached to cannon regardless of the size of the cannon as long as there is an indentation or taper. This method is far more stable than lifting it with two hooks attached to the ROV, as a slight CG offset from the center will cause the ROV to roll and the cannon to slide out. Using a independent lift bag with a noose also enables the ROV to release the lift bag, for it to stay down to complete other tasks and not be dragged up when lifting the cannon.

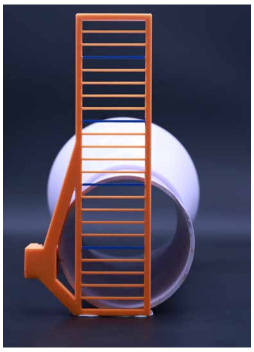


Figure 24. The cannon length measure agaisnt the cannon.

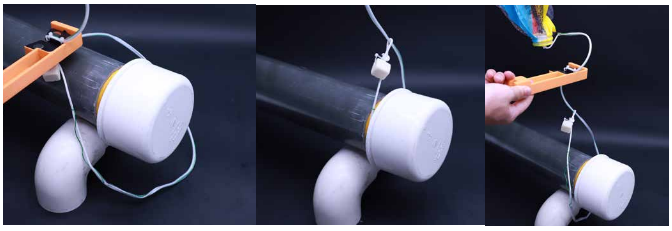


Figure 25. The process of retrieving a connon with the noose.

Cannon Shell Detector

The team created a cannon shell detector to test the composition of the cannon shells, to see whether or not it is ferrous. This was created by "sandwiching" 3 magnets spacing out evenly in between two long strips of duct tape. The detector is hanged freely underneath the ROV and when it contacts the cannon shells and stays attracted to the shell when its is pulled back by ROV, the shell can be determined to be ferrous and vice versa.

Figure 26. Cannon shell detector stuck to a ferrous cannon shell

Fabrication

Each part of the ROV has its own fabrication protocol, guiding the process of each part to be soldered, assembled, tested and waterproofed.

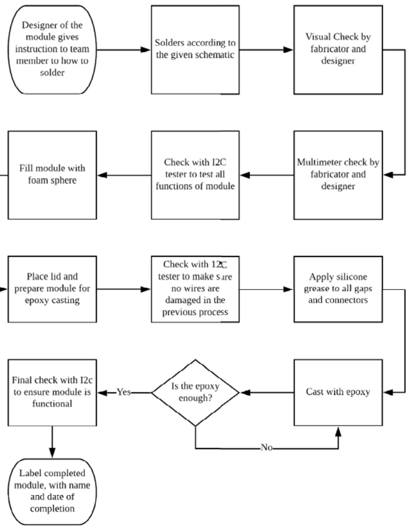


Figure 27. Generic Fabrication Protocol

Figure 27. Generic Fabrication Protocol shows the the process of how each module is made, this process was designed to ensure the reliability of every single module. Every fully tested part would be labelled containing the completion date and other details such as the I2C address. One of the team's main concern is waterproofing. When building the ROV the team went through many trials and errors before the team could achieve the best solution to fabricating each component.

Waterproofing of Plugs

Figure 28. Labelled diagram of a connector used on the ROV

Based on the previous pojects, the team continued the method of injecting fast curing epoxy into the body of the plugs to fill in the gaps between the wires and the walls of the plugs, in order to prevent water from flowing into the plugs and getting in contact with the wires where it would cause damage. As the team identified that it is hard to fill up all the gaps without having epoxy flowing down the pins to the other end of the plug, where the connection of the plug and socket takes place, petroleum jelly was first used to fill up the connection end of the plug. However, the team soon found out that petroleum jelly was not the ideal method, as it turns out that it degrades plastic, which is also the main composition of the plug. The team soon found out a better alternative that does not corrode plastic, silicone grease. Alike petroleum jelly, silicone grease is able to stop water from flowing in, since water and silicone grease are immiscible.

New Vs. Reused Components

Fish Logic strive for continual innovation brings improvement to all aspects of the ROV. The decision on whether the parts are reused depends on the new features, improvement in performance, effort needed to fabricate and financial cost of the components. This however means that almost all of Lusca's components are new, as only thrusters and cameras are refurbished to be compatible with the new systems and criteria. With the introduction of the 48V power system, it meant that all 12V power distribution modules are no longer compatible and are replaced. The Bi-electromagnets from Blazin's Hydra are compatible with the current Universal connectors, however, as the previous ones could not have its electromagnets controlled independently, new BEMs are produced with this new feature.

In-house-built Vs. Commercial Components

Fish Logic fabricate in-house parts to achieve innovative and unique functional parts that could not be commercially purchased. Performance of the components is then considered, especially its reliability. Fish Logic's fabrication capability is considered on whether or not if it is feasible for the members to build the part. Devices with complicated functionality, which exceeds Fish Logic's fabrication capability, such as cameras, monitors and the gamepad are purchased.

With the many new components that Fish Logic aims to improve on, the team first researches to check if they are commercially available. Parts that fulfills the required specification are compared to the resources and skills required to fabricating it in-house. The features, performance, cost and especially reliability of the parts are extensively evaluated before purchase. When no suitable parts are available, Fish Logic then considers whether the to fabricate them.

For the case of the thrusters, the commercial T100 thrusters have excellent performance, however the ESC that accompanies it has multiple technical issues. The original ESC modules were replaced with the in-house built ESC modules and integrated back onto the thrusters. This resulted with the thruster units with both the thruster and the ESC performing well.

Safety

Company Safety Philosophy

Safety precautions play an important role in every operation carried out by the team, as the team values the safety of all group members, the public and organisms. We ensure that all protection gears are used. All members are required to wear gloves, masks and safety goggles when handling dangerous and toxic chemicals, minimizing the risk of chemicals getting in contact with any personnel.

Safety in Workshop

When soldering, it is essential for members to wear safety goggles and mask, preventing smoke from contacting the eye, or inhaled. Room tidiness is also important, as working environment should be tidy to minimize accidents like trailing of wires and tripping over other tools and to prevent fire accidents. Members are required to wear a mask and gloves when handling resin or other adhesive chemicals, as it may cause burning or irritation on the skin. For operational safety protocol in lab and on deck please refer to Appendix 1: Operational and Safety Checklist.

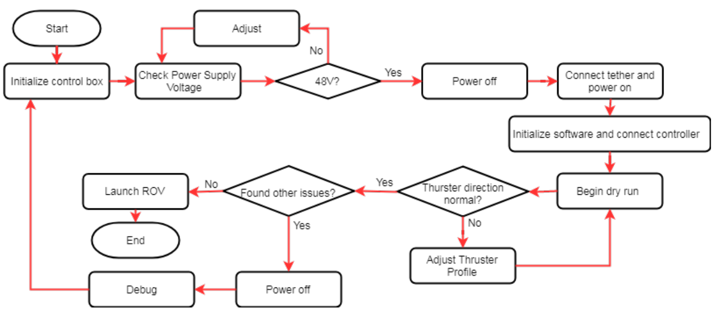


Figure 29. Flowchart of the testing protocol

Safety Features

To prevent accidents from occurring, a series of safety features were included on the ROV when designing. Due to safety reasons, if anything goes wrong within the control and no command is sent to the thrusters within 3 seconds, the thrusters will stop moving. An algorithm was implemented into the system to prevent current spikes that could damage the electronics system. Other safety features include:

Safety Features	Description
Black and Yellow hazard labels	Black and yellow hazard labels are wrapped around the thrusters to remind people in the surrounding of danger and to not o near, to avoid cuts caused by the propellers when power is given
Light	Light is installed on the ROV for it to be more noticeable in the surrounding to avoid accidents such as bumping into other ROVs, sea creatures or even divers
Thruster Shrouds	Thruster shroud are 3D printed and installed onto the thruster, the shrouds are up to the standards of IP20 to prevent fingers from getting near the propellers, significantly reducing the chance of injury caused by the propellers
No Sharp Edges	There are no sharp edges on the ROV, because all sharp edges are chamfered to avoid getting cuts and injuries
Handle	There is a handle installed to the top of the ROV, this allows the ROV to be handled with only one hand, and it keeps all hazardous modules away
Fast Blown fuse	Fast blown fuses are used to cut the circuit when the current exceeds the designed limit. It used to avoid accidents such as shock, due to the conduction through water by the exposure of wires or damage to the creature in water, which may result in death in worse case scenario
Kill Switch	A kill switch is installed into the control box to cut the power in emergency situations
Notification LED	There are notification LEDs installed onto different parts of the ROV to show that the ROV and the modules are powered

Table 3. Safety features of Electro Stargazer

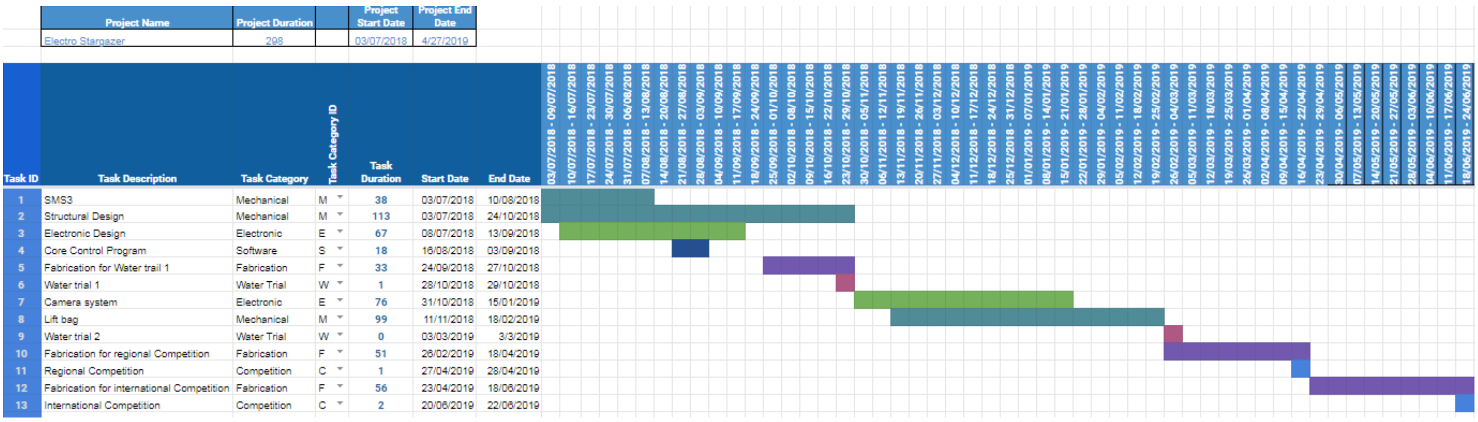
Project Management

A year-long schedule was maintained throughout the development of the ES. The first half was focused on developing a moving platform, with the development for the missions following immediately after the mission details were released. Water testing milestones were then set accordingly and a list of things to be completed was created for each milestone. Weekly plans were made using the list and ordered based on priorities, time duration and the people available for the tasks. The weekly plans allows the progress to be monitored carefully to know if it is late or not compared to the weekly deadlines and not only if it is done or not which have led to things being rushed to meet the water trial milestone.

The weekly plans are announced in weekly meeting allowing the team to reflect on the week's progress and ensure that all members are aware of the current state of the ROV's development. The department heads from the mechanical, electronic and fabrication department will then discuss tasks that involves multiple departments. After the meeting, the department heads will then assign the tasks based on each person's capability and interests to ensure the most suitable tasks is assigned to each person. Experienced members are responsible for the core design and the system integration of the ROV, where they will then delegate simpler tasks to newcomers, such as passive tools.

The design departments follow a flexible design procedure where design options are first conceptualized according to our design philosophy, then the prototype are tested and all its aspects are debated upon with the pilot's input for the next iteration. The fabrication department follows the prior mentioned fabrication procedures.

To allow collaborative working and prevent bottlenecks in programming, GitHub is used as the version control system, where every programmer has a separate local copy of the master code and only updates the master copy when the local copy has been tested to work. This ensure that the master copy is always working and available to everyone to work upon and not waiting for anyone to finish their part. Google Drive is used to keep the most updated version of documents and design files available to all members, regardless of location.



Project Name	Project Duration		Project Start Date	Project End Date
Electro Stargazer	298		03/07/2018	4/27/2019

Task ID	Task Description	Task Category	Task Category ID	Task Duration	Start Date	End Date
1	SMS3	Mechanical	M	38	03/07/2018	10/08/2018
2	Structural Design	Mechanical	M	113	03/07/2018	24/10/2018
3	Electronic Design	Electronic	E	67	08/07/2018	13/09/2018
4	Core Control Program	Software	S	18	16/08/2018	03/09/2018
5	Fabrication for Water trail 1	Fabrication	F	33	24/09/2018	27/10/2018
6	Water trial 1	Water Trial	W	1	28/10/2018	29/10/2018
7	Camera system	Electronic	E	76	31/10/2018	15/01/2019
8	Lift bag	Mechanical	M	99	11/11/2018	18/02/2019
9	Water trial 2	Water Trial	W	0	03/03/2019	3/3/2019
10	Fabrication for regional Competition	Fabrication	F	51	26/02/2019	18/04/2019
11	Regional Competition	Competition	C	1	27/04/2019	28/04/2019
12	Fabrication for international Competition	Fabrication	F	56	23/04/2019	18/06/2019
13	International Competition	Competition	C	2	20/06/2019	22/06/2019

Figure 30. Gantt chart

Critical Analysis

Testing and troubleshooting

Multiple water trials were conducted where the entire ROV and all its supporting system are tested. During water trials, the pilot gives feedback on the performance of the systems including the core control system and on how to tune the thruster profile, the ease of use of the manipulators, and any external factors affecting the ROV. The status monitor aids in debugging the control program and in tuning as well. The setup process provides insight into how the team can improve deployment of the system. For small scale or independent part water testing, a large kitchen sink is used frequently as it is fast and convenient and does not need to be setup unlike the inflatable pool used for full water trials.

During R&D, every new component is first tested independently to understand its behaviours and determine if it fits our criterias: function and part strength. Each piece of a part is developed and tested independently and added to systems with parts that were previously determined to work properly.

The whole electronic system of the ROV is then tested in smaller separate subsystems, including the I2C network, power distribution and the camera system. The full ROV system is tested in the order of: on land, in a large sink, in an inflatable pool, then finally in a 2m deep pool, where all functions capable of being tested in that environment are tested before moving to the next location. This is to have all parts tested in the most convenient and time-saving manner.

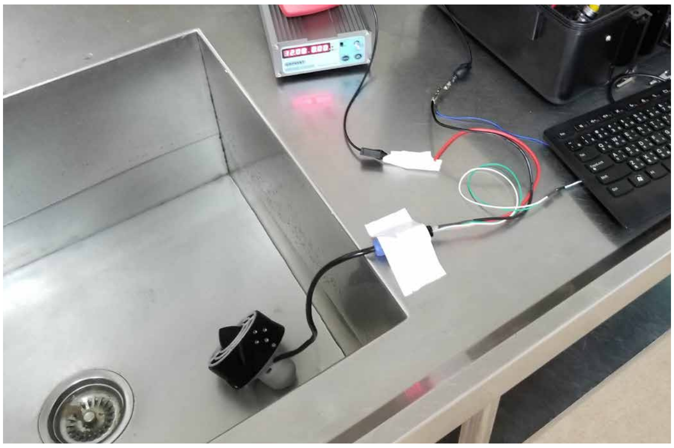


Figure 31. Testing thruster in sink.

Our initial design for retrieving the cannon was to use two hooks on the ROV as shown in Figure 32. Initial Cannon hook design. This was the first prototype option tested as it was the simplest in design and to operate. However, the weight of the

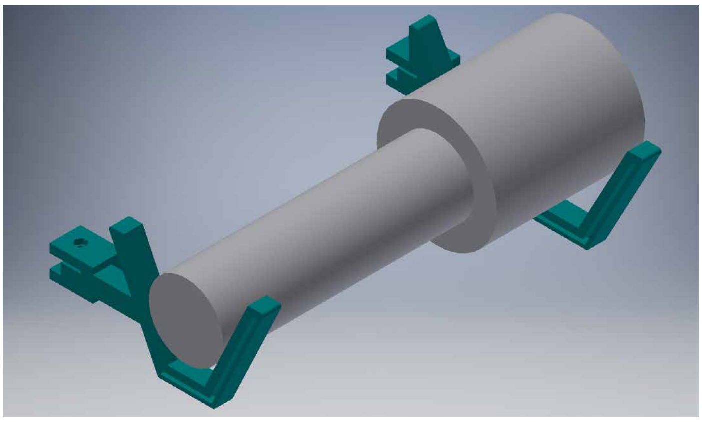


Figure 32. Initial Cannon hook design

cannon on the hooks placed too much stress on the mountings and the cannon may roll the ROV and slip out if the cannon's center of gravity is not exactly centered. The second method was then tested with two free-floating lift bags that wraps around the cannon so to not stress any mountings and with the intention that by wrapping around the cannon will hold the cannon from slipping out. However, kitchen sink test discovered that the cannon may still slip out when it is uncentered despite being half wrapped by the lift bags. Gravity hook and a noose were then considered as methods to hold the cannon securely without the possibility of it slipping out. The gravity hook design option was eliminated as the noose does not involve a complex mechanism and is more versatile for different cannon geometry. The noose works well when tested independently as well as during an integrated testing with the ROV in a water trial.

In order to streamline the troubleshooting for I2C devices, the I2C testers in the control box enables devices to be tested independently and conveniently. It would be tested first to see if the device is detectable in the network, this would test whether the device is alive or not. After that then the main functionality of the device would be tested.

With I2C being the core of the ROV's communications, it is crucial to monitor the health of the bus network. Errors in reading or writing to thrusters and other devices encountered are displayed, allowing for less apparent problems to be detected. The Pinger sends and receives packets from devices(clients) to calculate the round trip time on the network and monitor for any mismatch between the sent and received packets. A voltmeter on the 12V net, while monitoring for voltage drops or fluctuations which may affect the sensitive analogue cameras also enables further monitoring on the network when sending the readings to the master by checking for errors.

Challenges

Through developing a live onboard voltmeter, a large amounts of errors in sending I2C messages were discovered that increased as messages were sent more frequently. Our research results led us to discover and conclude that the "hardware bug" (where it does not support clock-stretching, which should enable clients to slow down the communications when necessary) on the Raspberry Pi (RPi) is likely the root cause. We then attempted to use software I2C to circumvent the hardware issue but found that its throughput was too low to handle anymore than 4 thrusters. The only option left was to find a hardware I2C replacement for the RPi. After research the RPi was replaced with Asus Tinkerboard since it is directly compatible with RPi but with a different CPU, and no programs or additional hardwares needs to be changed.

Solving the clock-stretching issue also solved the issue of occasionally losing control of the ROV which plagued our previous ROV as well. This led us to realise diagnostic tools' importance beyond its originally intended use as it may lead to insight to other parts of the system. With this realisation, an I2C pinger is implemented such that the control computer can monitor the delay and response time from the ROV.

One of the most significant challenge that the team facing this year is having four senior core members are graduating this year. New members in the team are also lacking competition experiences. Currently the seniors are trying their best to share their experiences and skills in design, fabrication, and maintenance with the other members hoping that they may pass it on, and keep up the quality of work. At the same time the senior members are also trying to train them for leadership roles and the command structure of a team. Ideally by the time the senior members leave the team, they should be able to understand the design of an rov, how to operate it, improve on current designs and also how to operate as a company.

Lessons Learnt

The importance of a strict R&D procedure especially on integrated testing were realised through attempting to implement I2C repeaters. It was intended for multiple repeaters to branch off and expand the I2C network from the sole onboard I2C extender. The repeaters were tested independently and behaved as expected. It was only during the middle of the fabrication process that it malfunctions. It took multiple weeks to identify the issue that the repeaters were not compatible with the extenders as each components worked when tested alone. The repeaters were then eliminated from the designs and now only uses extenders. Strict R&D procedure are now followed and a complete prototype must fully function before fabrication for the module begins.

With the size of the team doubled this year, we have learnt the methods needed to have efficient collaboration in a large team. Including improving the communication channels to enable parallel development involving multiple departments while minimising integration issues.

While training junior members, Fish Logic realised that the capturing of their interest is the most important factor. Large, long term goals have to be separated by shorter and smaller milestones or projects in order to boost their motivation with the sense of accomplishment. In addition, completing small projects under the guidance of experienced members teaches them the technical skills needed for larger and critical projects, as well as importance of meeting deadlines, responsibility and accountability.

Senior members have further refined their skills in 3D modeling, coding and fabrication. The programming team have learnt a new language, python, and gained valuable experience and understanding on developing computer vision (OpenCV) programs.

Future Improvements

Currently, all 3D printed parts have 100% infill density (completely solid) to prevent water ingress as the prints are water permeable under pressure. This is due to inevitable surface imperfections from being printed by FDM printers. Fish Logic has been experimenting on prints with lower infill densities (partially hollow) with a watertight shell. These new parts are created by printing with PolySmooth and treated in a ethanol bath to dissolve and form the waterproof outer shell capable of withstanding upto 8bars. The parts are now being tested for its long term durability while the fabrication techniques are being streamlined. If this technique is as promising as it appears, low infill prints will be fully implemented for the next ROV and may lower its framework's weight by 33%.

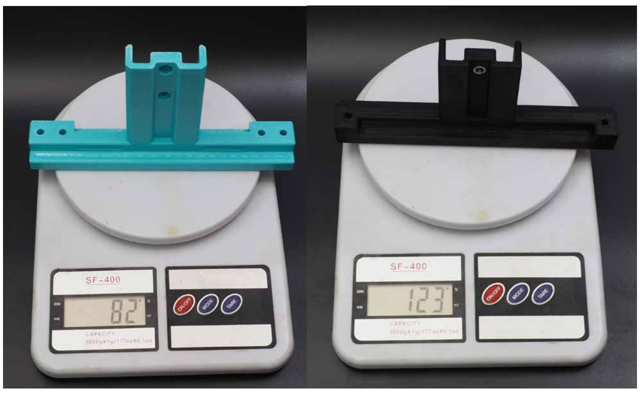


Figure 33. Weight comparison of polysmooth (left) and 100% PLA+.

Finance

As the project commences at the end of the previous competition, a budget is prepared by the team with estimated expenses based on the expenses of the last ROV. The income is estimated approximately to the funding and is included into the budget plan. As company with limited income, the team must stick to the budgeted expenditures. Whenever receipts are collected, it is entered in the budget, a project costing sheet and is compared against the budget to make sure that the capital is used properly and no extra capital is used.

Project Budget

Every year out mentor writes a proposal based on our project budget to the FDCT, our main income source to apply for the funding. FDCT has provided the team with a generous funding for our current project, the ES, as well as our previous projects. Our secondary source of income is from our school, Macau Anglican College, they fund our accommodations and travelling fee to the regional competition in Hong Kong.

School Name:	Macau Anglican College	**Reporting Period:**	From:	03/07/2018
Instructor:	Andy Tsui		To:	31/03/2019
Team Name:	Fish Logic			
Income				
Source				**Amount**
FDCT Grant				$ 30,000.00
Macau Anglican College Grant				$ 10,000.00
Enpenses				
Category	**Type**	**Descrition/Examples**	**Projected Cost**	**Budgeted Value**
Hardware	Re-used	Joystick	$ (350.00)	-
Hardware	Purchased	Monitor	$ (2,000.00)	-
Travel	Purchased	Transportation to Hong Kong	$ (1,560.00)	$ (1,560.00)
Travel	Purchased	Accomodation in Hong Kong	$ (7,200.00)	$ (7,200.00)
Hardware	Purchased	Waterproof plugs and general electrical components	$ (6,000.00)	$ (6,000.00)
Hardware	Purchased	Blue Robotics thrusters	$ (6,560.00)	$ (6,560.00)
Hardware	Purchased	3D Printer filaments	$ (4,000.00)	$ (4,000.00)
Hardware	Purchased	General mechanical parts	$ (5,000.00)	$ (5,000.00)
Sensors	Purchased	Task specific sensors	$ (4,000.00)	$ (4,000.00)
Total Expenses				$ (36,670.00)
Total Expneses-Re-used/Donations				$ (2,350.00)
Total Fundrasing Needed				$ 5,680.00

Table 4. Project budget table. (All currency in HKD)

Project Costing

School Name:	Macau Anglican College				Reporting Period:	From:	03/07/2017
Instructor:	Andy Tsui					To:	31/03/2017
Team Name:	Fish Logic						
Date	**Type**	**Category**	**Expense**	**Description**	**Sources/Notes**	**Amount**	**Running Balance**
20/02/2018	Purchased	Electronics	Electromagnet			$ (270.00)	$ (270.00)
2/20/2018	Purchased	Electronics	Optic Fibre & modem			$ (700.00)	$ (970.00)
20/02/2018	Purchased	Hardware	Monitor			$ (1,020.00)	$ (1,990.00)
03/07/2018	Re-used	Hardware	Joystick	PS4 Controller	For control box	$ (350.00)	$ (2,340.00)
03/07/2018	Parts Donated	Electronics	Arduino & Digispark			$ (1,000.00)	$ (3,340.00)
03/07/2018	Cash Donated	Funds	-	Funds from Macau FDCT	Used for vehicle construction	$ 30,000.00	$ 26,660.00
04/07/2018	Re-used	Electronics	Raspberry Pi		For control box	$ (250.00)	$ 26,410.00
30/07/2018	Purchased	Electronics	Step Down Converter	48V to 12V		$ (1,200.00)	$ 25,210.00
31/07/2018	Purchased	Electronics	Power Supply	60V power supply		$ (950.00)	$ 24,260.00
02/09/2018	Purchased	Electronics	ESC			$ (1,600.00)	$ 22,660.00
06/09/2018	Purchased	Electronics	Tether			$ (1,300.00)	$ 21,360.00
02/10/2018	Purchased	Hardware	Control box			$ (380.00)	$ 20,980.00
09/11/2018	Purchased	Electronics	Electrical terminal			$ (130.00)	$ 20,850.00
09/11/2018	Purchased	Electronics	Gear box			$ (300.00)	$ 20,550.00
11/11/2018	Purchased	Electronics	Camera Switcher			$ (210.00)	$ 20,340.00
11/11/2018	Purchased	Hardware	3D print filament			$ (3,900.00)	$ 16,440.00
11/11/2018	Purchased	Hardware	3D print UV resin			$ (250.00)	$ 16,190.00
11/11/2018	Purchased	Electronics	I2C Extender			$ (540.00)	$ 15,650.00
23/11/2018	Purchased	Hardware	Camera			$ (700.00)	$ 14,950.00
12/12/2018	Purchased	Hardware	PU Foam			$ (130.00)	$ 14,820.00
12/12/2018	Purchased	Hardware	Waterproof canister			$ (600.00)	$ 14,220.00
12/12/2018	Purchased	Electronics	Raspberry Pi & camera			$ (400.00)	$ 13,820.00
27/12/2018	Purchased	Hardware	Blue Robotics Thrusters			$ (6,560.00)	$ 7,260.00
03/01/2019	Purchased	Sensors	pH Probe			$ (250.00)	$ 7,010.00
22/01/2019	Purchased	Electronics	Waterproof plugs			$ (2,500.00)	$ 4,510.00
3/13/2019	Purchased	Travel	Accomodation in HK	12 beds x 2 nights	For regional	$ (7,200.00)	$ (2,690.00)
13/03/2019	Cash Donated	Funds	-	Funds from Macau Anglican College	Used for travel	$ 10,000.00	$ 7,310.00
26/4/2019	Purchased	Travel	Transportation to HK	Round trip tickets to HK	For regional	$ (1,560.00)	$ 5,750.00
Total Raised							$ 40,000.00
Total Spent							$ (34,250.00)
Final Balance							$ 5,750.00

Table 5. Project costing table. (All currency in HKD)

Acknowledgement

MATE Centre - Sponsoring this year's competition.
IET Hong Kong- Hosting the regional competition.
FDCT - Generous donation of funding.
RS - Gold sponsors of the Hong Kong regional competition.
HK Electric - Silver sponsors of the Hong Kong regional competition.
CLP - Silver sponsors of the Hong Kong regional competition.
HKUST - Technical sponsors of the Hong Kong regional competition.
Macau Anglican College (MAC) - Funding our accommodations, and workshop space.
Mr. Andy - Our mentor for giving advices.
Mr. Ryan - Lab assistant at MAC for assisting us in experiments.
Mr. Pong - Maths teacher at MAC for giving advices.
Mr. Carlos - Lab assistant at MAC for giving advices.
Autodesk - Free student license software.
Our Families - Their continued support and encouragement.

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Appendix 1: Operational and Safety Checklist

In Lab:

- Saftey gears are worn depending on the situation
- Area clear/safe (no tripping hazards, items in the way)
- Equipment are kept properly
- Keep the workshop tidy
- Make sure you have someone working with you

Soldering:
- Wear safrty googles and mask
- Clear the table
- Turn on the ventilation

Handling Resin:
- Wear mask and gloves
- Turn on ventilation
- Clear the table
- Prepare tissue paper

On Deck:

Setting Up on Deck:
- Area clear/safe (no tripping hazards, items in the way)
- Tether is laid out and managed by a team member
- Plugs and sockets are connected securely
- Verify power switch is off
- Thrusters are properly shielded
- No exposed copper or bare wires
- Screws and nuts are tight
- Tether securely connected to ROV
- Single inline 30A fuse in place

Power-Up:
- Ensure all team members are attentive
- Call out, “Power on”
- Power on
- Control computers up and running
- Call out, “Test thrusters”
- Perform thruster test
- Verify video feeds
- Test active manipulator

Launch
- Call out, “Prepare to launch”
- Deck crew members handling ROV call out, “Ready”
- Launch ROV

ROV Retrieval:
- Pilot calls out, “ROV surfacing”
- Deck crew calls out, “ROV on surface”, when ROV reaches the surface
- Stop thrusters
- Remove ROV from water

Loss of Communication
- Restart ROV
- Check status light
- Restart control program
- If communication restored, resume mission

Maintenance:
- Verify thrusters are free of foreign objects and are spinning freely
- Visual inspection for any damage
- All cables are neatly secured
- Screws and nuts are tight