CMA UNDERWATER EXPERT LTD.

ETA

TECHNICAL DOCUMENTATION

2018 MATE INTERNATIONAL ROV COMPETITION

Crew Members:
CEO:
Khalil CHOY, Grade 11, New
Secretary:
Louise LO, Grade 11, Returning
Head Marketing Executive:
Beth AU, Grade 11, Returning
Marketing Executive:
Tracy LI, Grade 11, New
Head Mechanical Engineer:
Paul CHOW, Grade 11, Returning
Mechanical Engineers:
Jacky SHUM, Grade 10, New
Kelvin KO, Grade 11, Returning
Ming NG, Grade 11,New
Gordon LO, Grade 8, New
Electrical Engineers:
Jerry LUM, Grade 11, Returning
Terry AU, Grade 7, New

Mentors:
Andy LAM
Crystal WONG
Darren CHAN
Kenny WONG
King DANG
Seth LEUNG
Torres LEUNG

Supervisors:
Man Yuen CHEUNG
Queenie YEUNG
Shawna TSANG

HONG KONG

CMA SECONDARY SCHOOL, CMASS ROBOTICS TEAM

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Introduction

Abstract

Another year in ROV research and development marks our 11th year around. This year, we, CMA Underwater Expert Ltd., is proud to present our newest creation, ***Eta***. We answer to the request of the University of Washington for a vehicle fit for missions headed to the Pacific Northwest, where the terrain challenges navigators with snow, volcanoes, fjords, mountain ranges, and possible earthquakes.

With more than a decade with Remotely Operated Vehicles (ROV), we aspire to outdo our old designs every year in terms of size, efficiency, durability, and stability. ***Eta*** is specifically designed for this year's tasks. Said tasks include scouting and retrieving seabed wreckage and debris, installing and releasing seismometers and other research mechanisms, and even assembling energy generating devices, such as tidal turbines.

Standing at 520mm x 420mm x 430mm , and weighing 11.4kg, ***Eta*** is small for its type but has everything you need. ***Eta*** is equipped with 6 Seabotix thrusters and has a frame made of High Density Polyethylene (HDPE), thus the need for buoyancy is reduced, making the ROV much more compact while enabling multi-directional movement.

Specially developed mission tools, such as an inflatable air bag, an acoustic release seismometer, and distance calculation software were custom made for this year's tasks, involving measuring, transporting and maneuvering props.

With the combined efforts of 11 company members, we are confident that ***Eta*** will answer to this year's requests. This technical document details the technical components of ***Eta***, CMA Underwater Expert's brainchild of 2018.

Figure 1: Team photo
(Top left) Ming NG, Tracy LI, Beth AU, Louise LO, Khalil CHOY
(Bottom left) Gordon LO, Kelvin KO, Terry AU, Jerry LUM, Jacky SHUM, Paul CHOW

Design Rationale 04

A. Aim

This year, CMA Underwater Expert Ltd. focuses on achieving three objectives.

The primary objective is to build an integrated ROV which is comprehensive yet miniature and lightweight. ***Eta*** targets at maximizing its size score by fitting into the smallest ring, which measures 60cm in diameter, gaining us 10 extra points.

The second objective is to devise a good troubleshooting mechanism that makes our ROV safe and reliable. This year, we made use of electromagnetic and acoustic activation in our OBS, a major tool for a mission bearing a heavy weighting, so detecting any glitches in the OBS as soon as possible is crucial to the success of our mission.

Regarding non-technical areas, we aim to incorporate more female members in our team, as we have noticed that our team has long been male-dominated. Recruiting more female members provides better public-relationship opportunities for the team, upping our networking.

B. Design Process

In pursuit of creating an ROV which is compatible with our company's standard and the requirements of MATE 2018, we started our evaluation soon after the local competition, listing out the deficiencies and potential problems that we would likely encounter in our existing design. Mission tools were then improved altogether with buoyancy modifications. Intense training was arranged for drivers to keep them in best condition and boost their performance in the competition.

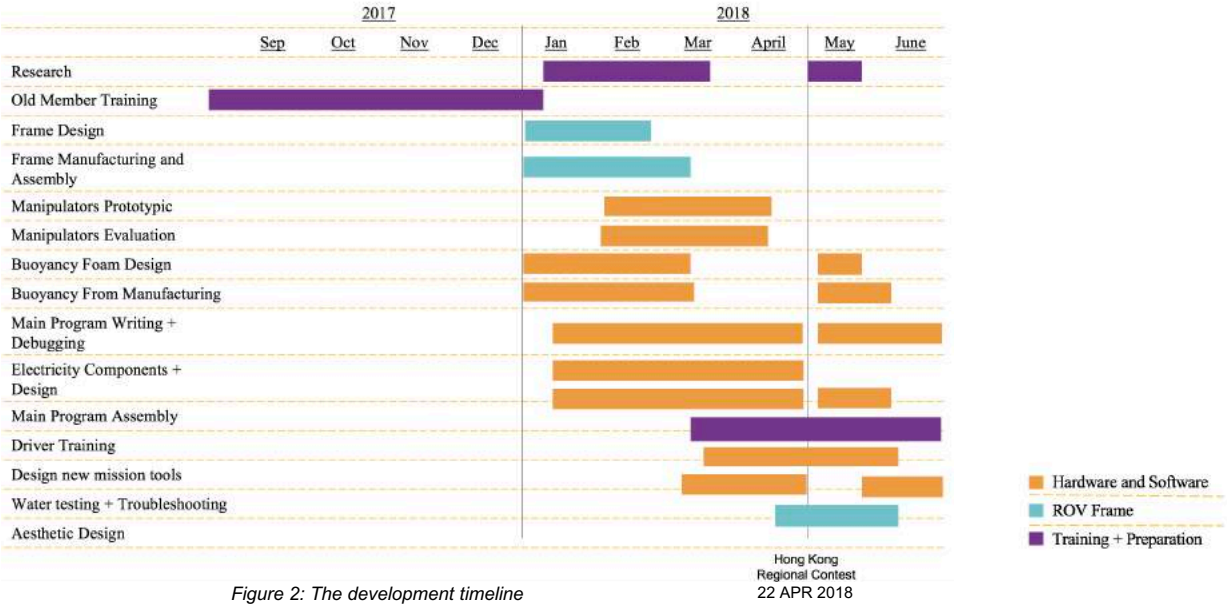


Figure 2: The development timeline

C. Design Philosophy

In order to produce the most efficient ROV for customers with various needs, ***Eta***'s design philosophy focuses on versatility. ***Eta*** adapts readily to many different environments, owing to its detachable and interchangeable subframes. Its main frame houses its thrusters, cameras, and circuit boards, where its manipulator is situated in its subframe. Depending on terrain and task type, our company can develop alternative subframes with different functions and payload tools, like how different lenses can be fitted onto a camera depending on the cameraman's needs. Should observation be the only function required, we can even opt to forgo its subframe, further reducing ***Eta***'s weight to a record low of 8kg. We have also built in special holders for our payload tools on ***Eta***, so as to reduce our dependence on the manipulator for transport.

D. Overview (Sketches and Draft of *Eta*)

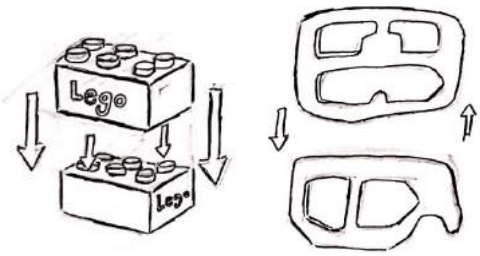


*Figure 3: Concept drawing of **Eta**'s frame*

*Figure 4: Concept drawing of **Eta***

Once the design team validated the concepts through sketches (as shown in Figure 3 and Figure 4), a detailed Computer-Aided Design and Drafting (CADD) model in both 2D and 3D was used to simulate our initial design. Autodesk Fusion 360 was used to connect the entire product design & development process.

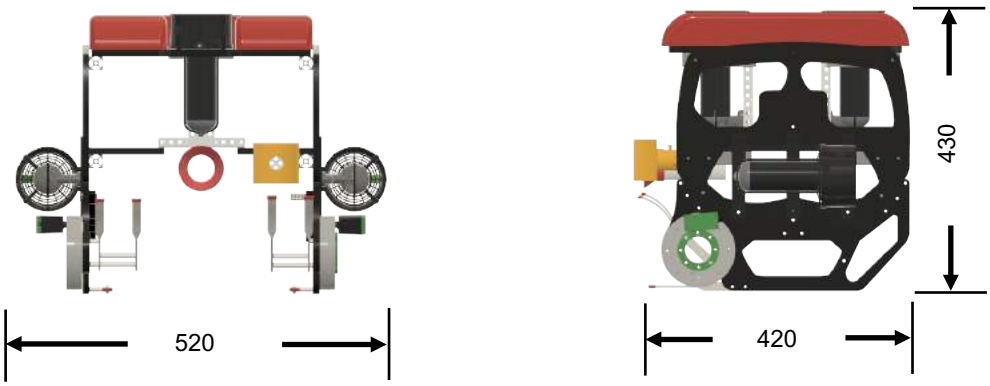


*Figure 5: CAD model of **Eta***

In order to maximize the efficiency of the design process, we used a CAD model to illustrate the ideas of our ROV, allowing our members to share ideas and discuss freely while necessary changes were incorporated until the ideal design was achieved.

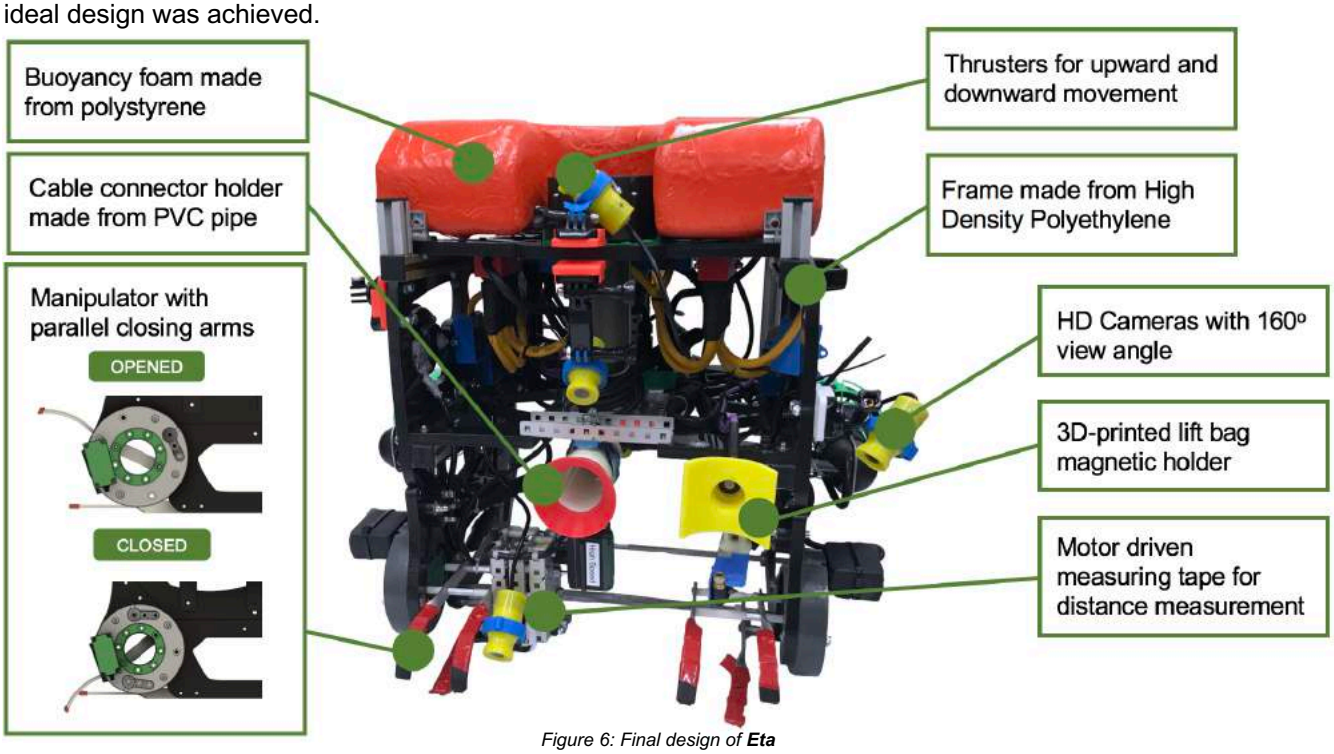
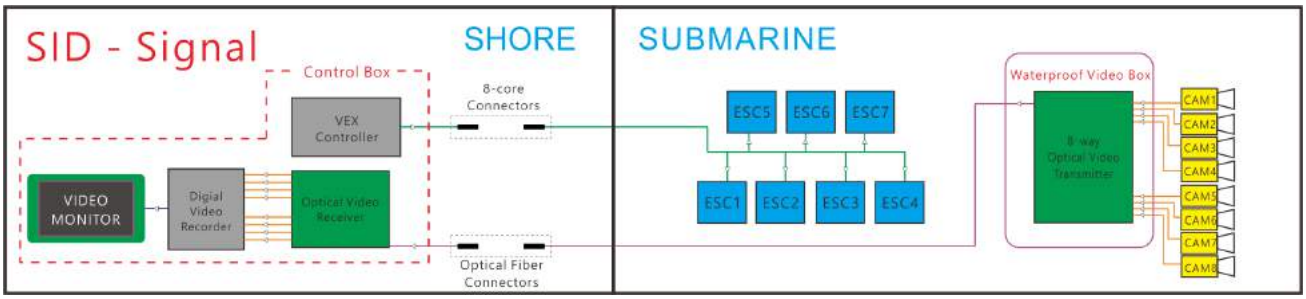
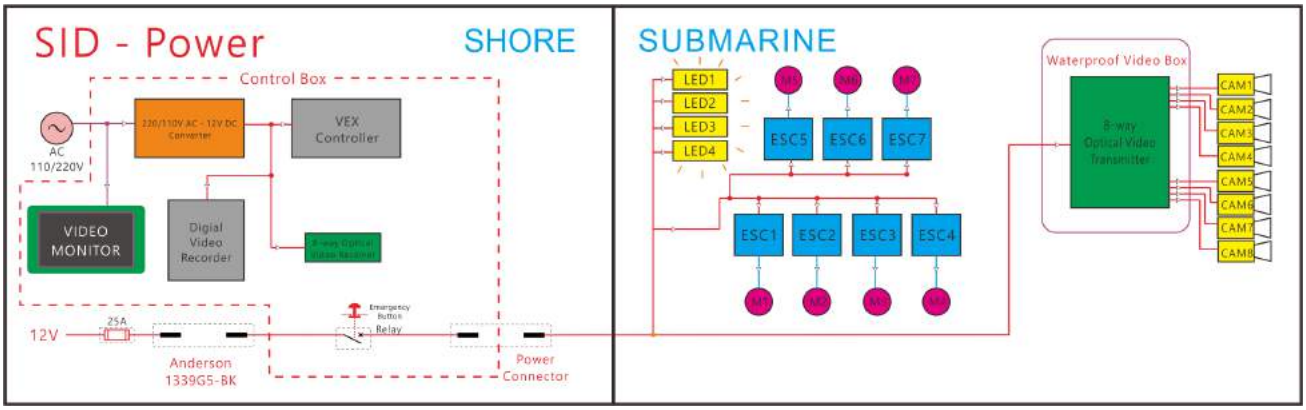
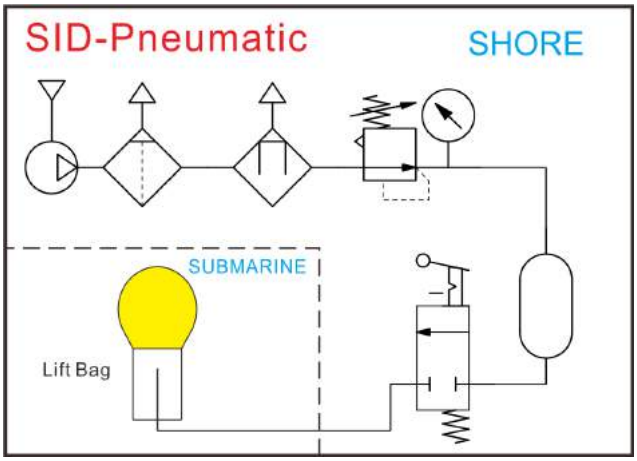


*Figure 6: Final design of **Eta***

E. System Interconnection Diagram (SID)







Fuse Calculation			
Component	**Power(W)**	**QTY**	**Total(W)**
Seabotix BTD-150 (M1-M4)	25	4	100
Camera (CAM1-CAM8)	1	8	8
Optical Video Transmiter	13	1	13
LED (LED1 - LED4)	1	4	4
Manipulator(M5,M6)	20	2	40
E-Magnetic (M7)	10	1	10
		Total	175
Max. Curret A(max) = Total Power / 12V			
A(max) = 175/12=14.6A			
Fuse value =14.6*1.5=21.9->Use 25A fuse			

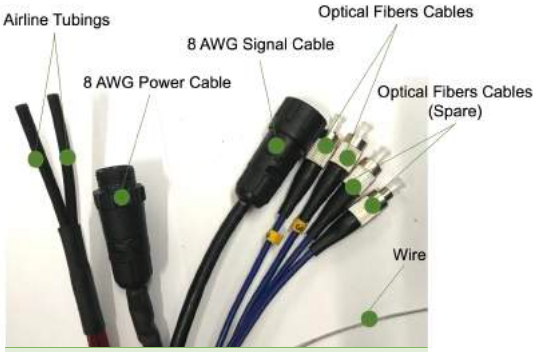
*Figure 7: SID of **Eta***

Using optical fibers to transmit camera signals conducively reduces interference as well as keeps ***Eta*** light and the tether thin. The control signal from VEX controller to the Electronic Speed Controllers (ESCs) are transmitted using 8-core silicon coated wires for the greatest flexibility and stability.

One emergency stop button and a 40A SSR (Solid State Relay) are used to rapidly disconnect the power provided to the ROV in case of emergency.

F. Tether

Eta is connected to a 15-meter long tether, consisting of one 8 AWG power cable, four optical fiber cables, one 8 core-signal cables, and two airline tubings and one wire. The one power cable is used to provide power to ***Eta***, while one 8 core-signal cable is used for communication and the other serves as a backup for emergencies. To ensure stable power provision, we have opted for an 8 AWG power cable over a thin silicone cable, despite silicone cables being thinner and lighter. Since we are using eight digital cameras, two optical fibers are used to handle camera signals. A wire prevents the tether from cracking. An airline tubing supplies air used to inflate our lift bags used in Task 1, while the other acts as a spare.



Diameter (mm)	27
Length (m)	15
Total Weight (kg)	6
Cables Included	1: 8 AWG Power Cable 1: 8-Core Signal Cable 4: Optical Fiber Cables 2: Airline Tubings 1: Wire

*Figure 8: Tether specifics of **Eta***

From last year's experience, we encountered a critical misconnection when assembling our wires, which led to a major break down during our second product demonstration. Cracks and leakages are also possible when handled carelessly. During our pool trials, there was a crack found in our signaling wire, where the water leak led to short circuiting that jumbled up our direction signals. To counter the problem, a substitute signal cable was made to rectify the faults in connection, and extra care was taken in waterproofing our parts.

For safety, The section of tether closest to the ROV is attached with a tether locker (Figure 9) to avoid it from snagging on the ship and threatening the success of the mission.

Figure 9: Photo of tether locker

G. Frame

To reduce the weight and size of the ROV without sacrificing strength and durability, ***Eta***'s frame is built from high density polyethylene (HDPE). Using HDPE for ROV frames is becoming increasingly common. HDPE is preferred over aluminum due to its low density, low cost, and high manufacturability. Compared to the density of aluminum (2.70g/cm³), the density of HDPE (0.93 to 0.97 g/cm³) is way lower, even lower than that of water (1 g/cm³), which is favorable to, and aids the buoyancy system of ***Eta***, as its dependence on a large float or ballast is greatly reduced, making ***Eta*** even more compact. HDPE can be easily manufactured by using a Computer Numerical Control router (CNC router), and the rigidness of HDPE is more than capable of protecting the ROV's core, keep interior structures intact. HDPE is also cheaper than other materials. After careful consideration, HDPE has been chosen as the preferred choice of material for ***Eta***'s frame.

There are also a few other distinctive characteristics of ***Eta***'s frame. The corners of ***Eta*** are rounded as a safety measure, to ensure that the ROV is safe to handle. The hole for the thrusters are universal, fitting both SeaBotix and BlueRobotics thrusters, making the frame compatible with different parts.

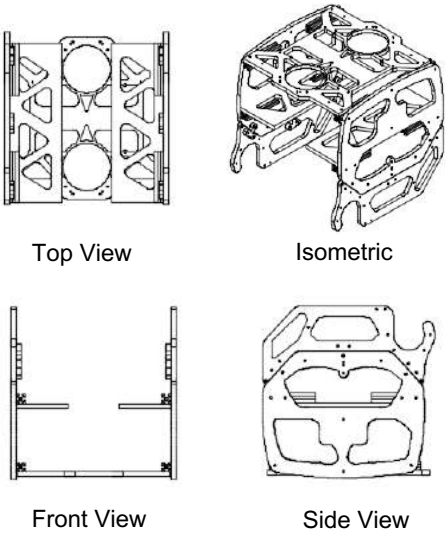


*Figure 10: Overview of **Eta**'s frame*

Design Rationale

The open frame of ***Eta*** provides minimal obstruction and has enough space for the installation of the electronic speed controllers, optical fiber receivers, and six thrusters. All fixed electrical components are been placed in the main frame to condense all critical parts. The bottom part of the frame allows room for the installation of an interchangeable subframe. This year's subframe houses two manipulators, their turntable bearing kits, and a measuring tape. In cases where maximum agility is required, the subframe is completely removed. An empty bottom part reduces weight and allows water convection to occur, further minimizing water resistance.

We have been using Autodesk Flow Design to help simulate the performance of the ROV underwater and we keep refining and improving its design and its performance in reducing water resistance. Using the data analysis provided by Autodesk Flow Design, we are able to conduct numerous tests, experiments and refinements until the ultimate design, ***Eta***, comes to place. ***Eta*** has now proven itself small but precise, simple but powerful, and able to work efficiently with variable water flows. Once the design is finalized, it will be sent to a manufacturer to be milled into the desired shape, to ensure better quality of the structure.

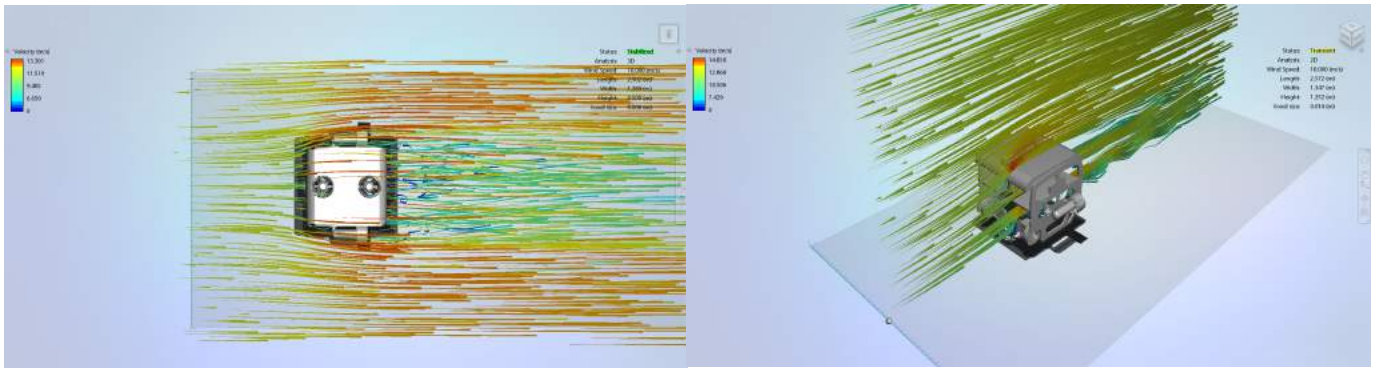


*Figure 11: Flow test simulation of **Eta***

The most efficient feature of the frame of ***Eta*** is its easily detachable compartment, which allows effective installation and maintenance. It can be separated into two sections within seconds by detaching or disconnecting any other components such as buoyancy board and clip by removing six screws. This feature enables the clear monitoring of all components during mission and makes repairing convenient. The quickly detachable mechanism is designed for easy shipping, and to prevent any possible damage caused by logistical issues.

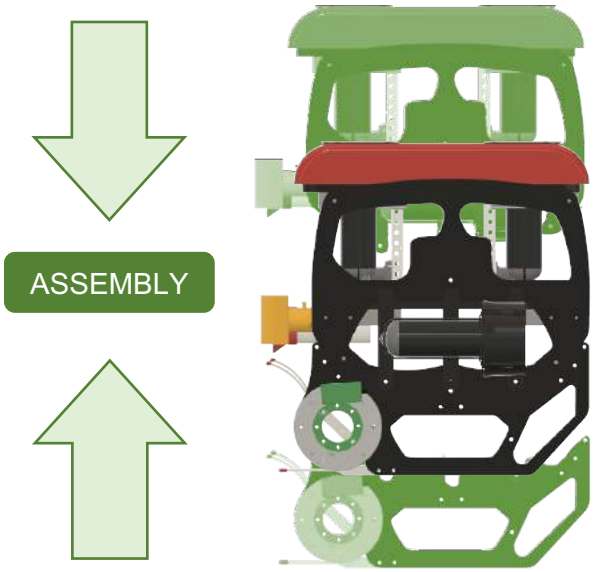


*Figure 12: **Eta**'s quickly detachable subframe*

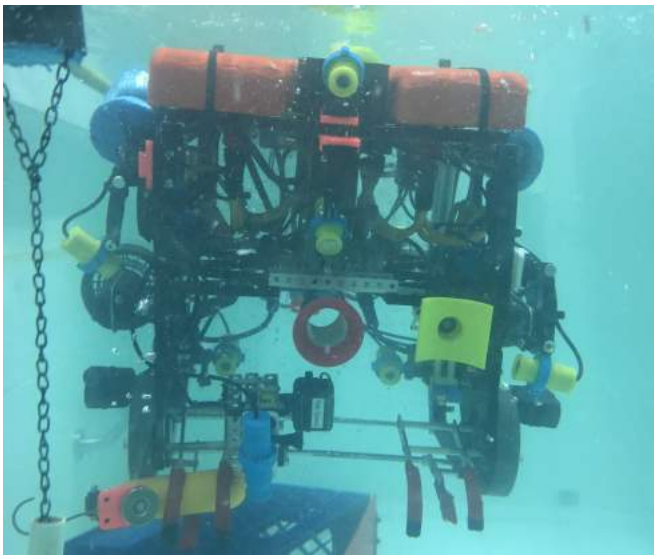


*Figure 13: Front shot of **Eta** in water*

H. Electrical Distribution Control Panel (EDCP)

The Control Panel is the main control system for ***Eta*** that gathers the Tether Control System (TCS) on shore, communications, tether connecting to the ROV, and onboard electronics together. For safety concern and convenient troubleshooting, all onshore electronics are gathered in the flight case for better integration.

A 25A fuse is included at the side of the power input is a safety feature to minimize the happenings of accidents under operation. In addition to the 25A fuse, there is a power toggle button for all major networking components inside the TCS.

Voltage and current meters are installed to allow the pilots to monitor for power issues such as discharged batteries and short circuits. Signals of the cameras are being transmitted from a optical fiber transmitter which is installed on ***Eta***. The optical fiber transmitter can transmit eight camera signals, where optical fiber receivers convert the cameras' signals into video images. The video images are sent to the Digital Video Recorder for grouping the video images to display all videos on the same monitor which provides the pilots a full and clear picture during operation.

Figure 14: Features of EDCP

Two VEX controllers are installed in the Control Panel to send thrusters signals to the mini Electronic Speed Controllers, then Control the thrusters. The 24-inch monitor can is mounted for better scanning during operation. All the electronic components in the Control Panel have been are newly bought to replace the old and faulty ones.

A separate Surface Pro notebook installed with Windows 10 is used for data analysis, software troubleshooting and running the ScreenRuler application. The notebook is only 292mm x 204mm x 85mm in size, which makes it very convenient for carrying and usage.

I. VEX Controller Kit

The ROV is controlled by one VEX Controller Kit which controls the motions of ***Eta*** through its 6 thrusters for movement, two turntable bearing kits for the manipulator, and one turntable bearing kit for the measuring tape. These control system consists of a 750MHz RF transmitter, a receiver remote control, a radio transmitter unit, and a compatible receiver unit. The presence of such units allows easier accommodation for future expansions of the ROV subsystems. What is noteworthy is that the VEX controller joysticks are among the small number of components purchased from commercial companies. Since our members are highly experienced drivers, are very familiar with using their controllers given their experience from participating in VEX challenges.

J. Electronic Speed Controllers (ESCs)

Four SeaBotix thrusters, together with the manipulator and turntable bearing kit are controlled by eight waterproofed 1060 Brushed Electronic Speed Controllers (ESCs). Weight is of paramount importance when mission requirements are concerned.

The brushed ESC is 60A, aiming to control the moving speed and direction of the thruster. While the ESC is running, an ongoing beeping sound and LED light beam will be produced, which serves as an indicator for our pilot that the ESCs are functioning normally. If the light goes off, it also serves as a means troubleshooting mechanism, indicating that the ESC has malfunctioned and repair is necessary.

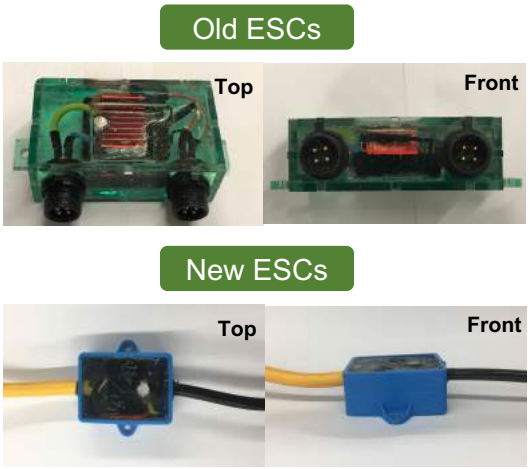


Figure 15: Comparison of old and new ESC Boxes

Previously we sealed the ESCs individually in their own acrylic glass boxes, creating a mini water-proofed housing for each ESC and filled each with epoxy, and then installed them on ***Eta***. This year we used the same principles, but further reduced their weight and manufacturing time 50% using 3D-printed casings instead of acrylic glass boxes. Filling the ESCs with epoxy also resolves any complications brought about by the water-absorbing properties of PLA, the filament used in 3D-printing.

If one of the ESCs appear to malfunction, we can replace it with another spare mini ESC box conveniently. This is a standardized design and can be easily replicated. Since manufacturing ESCs are simple and fundamental, ESC making workshops are also used to train our younger members, where their finished products contribute to ***Eta***'s parts, hence they are able to participate in the process of ROV making, and thus granted a sense of accomplishment.

K. Thrusters

Eta is equipped with four SeaBotix thrusters. Two are mounted horizontally to allow cardinal movement at 2x thrust. Two thrusters are mounted vertically for quick levitation and descending of ***Eta*** in water.

At present, one vertical thruster is mounted at the front, and the other at the back. Previously, the thrusters were positioned side by side, which concentrated the weight of our manipulator in front of the thrusters, posing a possible hazard of tipping over the ROV, tangling its tether on itself. Our current design puts one thruster directly above the manipulator, so in case of imbalance, the power of the thrusters can be adjusted immediately to help ***Eta*** maintain balance and equilibrium.
(pic needed)

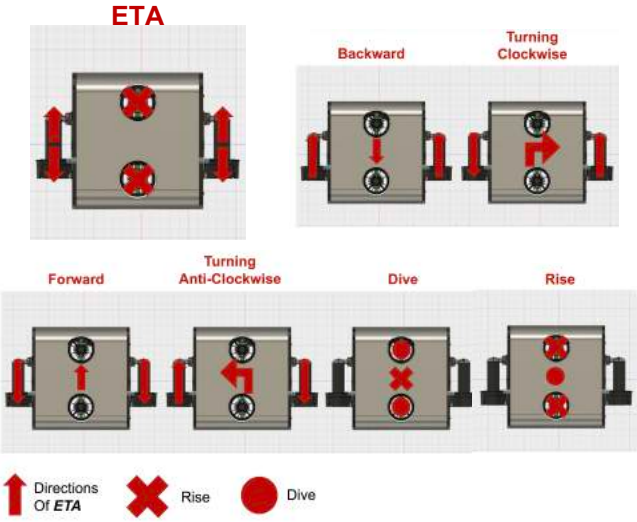


*Figure 16: Explanation of **Eta**'s propulsion system*

Each thruster provides at maximum 5 pounds of forward thrust, and 4 pounds of reverse thrust. With an operating power of 12VDC and a maximum current of 11.5Amps, it satisfies ***Eta***'s power requirements. Each thruster is mounted onto the frame with screws. A shroud covers each thruster to minimize debris obstruction, along with a warning sign to remind our team members to take extra care. In adherence to this year's new IP-20 solid particle protection regulation, extra shrouds with mesh openings finer than 12.5mm were designed. These shrouds were first designed as a CAD drawing, and later realized by printing them in the material PLA+(Polylactic Acid Plus) through 3D-printing technology.

L. Buoyancy

Eta is fitted with a buoyancy float system specifically designed to neutralize the ROV's buoyancy. The buoyancy foam is cut from an extruded polystyrene foam board since it is affordable, easy to shape and its peerlessly low density material neutralizes ***Eta***'s weight in the water. ***Eta*** is tested for its water weight, then an adequate buoyancy is made to counter its weight.

Our company tests the buoyancy float by installing it on ***Eta***, with all the other components installed, and then testing it in our own test pool. This testing method calculates buoyancy more accurately than by meer estimation. The weight in water of ***Eta***, before the addition of the float, was 11.4kg. ***Eta*** relies on its H-shaped buoyancy foam, approximately 300mm x 330mm x 60mm in size, for a total of 3.89kg of buoyancy, compensating for the vehicle's wet weight. The shape of the buoyancy foam is streamlined and moulded to hug the shape of ***Eta***, so as to reduce water resistance as much as possible. The floatation piece is cut by hand, then fiberglassed with bandages and epoxy, and sanded to remove any imperfections or rough surfaces. A second layer of epoxy is added to smoothen the surface and harden the buoyancy board to withstand high water pressure. Its fluorescent orange color makes our team members more alert and aware of safety due to its bright color.

*Figure 17: Kelvin KO cutting away extra bandages from **Eta**'s buoyancy foam*

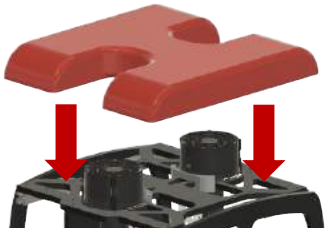


*Figure 18: The buoyancy board neutralizes the weight of **Eta** in water with a total of 3.89kg.*

M. Software Flow

RobotC is a free coding software we use to control ***Eta***. Writing the RobotC code controls the sequence of how the thrusters of the ROV function, which in turn controls ***Eta***'s manipulator and how its thrusters help the ROV navigate.

RobotC is crucial to the upkeep of our thrusters. Before inputting the values controlling the thrusters, RobotC double-checks that the values fall within the safety parameters of the thrusters to prevent overload. The values are then output through PWM (Pulse Width Modulation) signals, which is a modulation technique used to encode a message into a pulsing signal of controlled wavelengths, ensuring that thrusters are not overloaded. This helps mitigate the risk of having to repair our ROV's thrusters mid-mission.

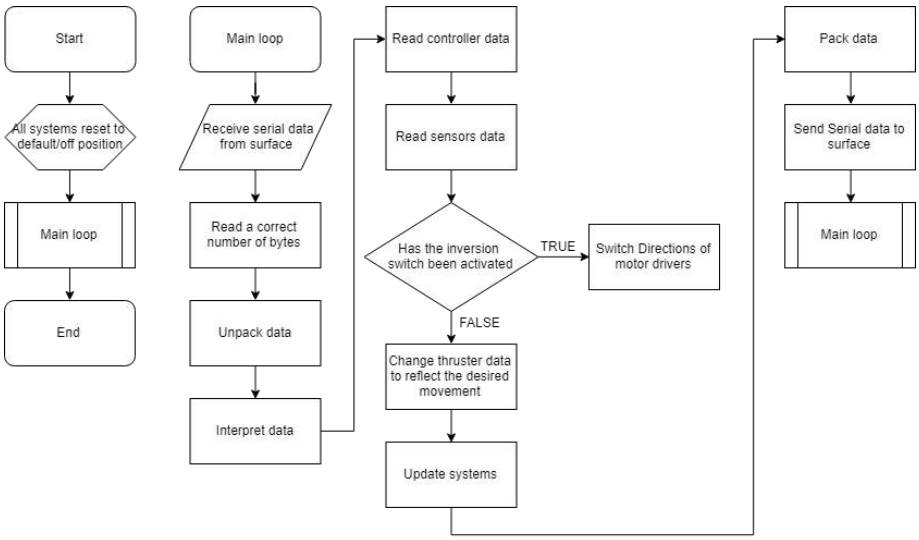


*Figure 19: Program flow of **Eta**'s control*

N. Mission-Specific

Cameras

During missions, glitch-free operation relies heavily on the upkeep of our cameras. Apart from observing our surroundings and helping Eta maneuver in water, there is a lot of identification work required for this year's missions, such as identifying tail structures of aircraft wreckages in Task 1.

From our experience in the past few years, our ROV has now evolved to using a total of 8 images. This number of images maximises our field of vision, and helps reduce as many blind spots as possible.

This year, we encountered a couple of challenges with our cameras. Compared to previous years, this year's props are considerable large and irregularly shaped, like the I-AMP and the tidal turbines, which had a tendency of blocking one or more of our cameras. The task requirements also varied from transporting loads to fine maneuvering of locks and latches (e.g. Task 3). To solve the mentioned problems, we had to reposition our cameras, so that they provided all-rounded visibility coverage from near to far.

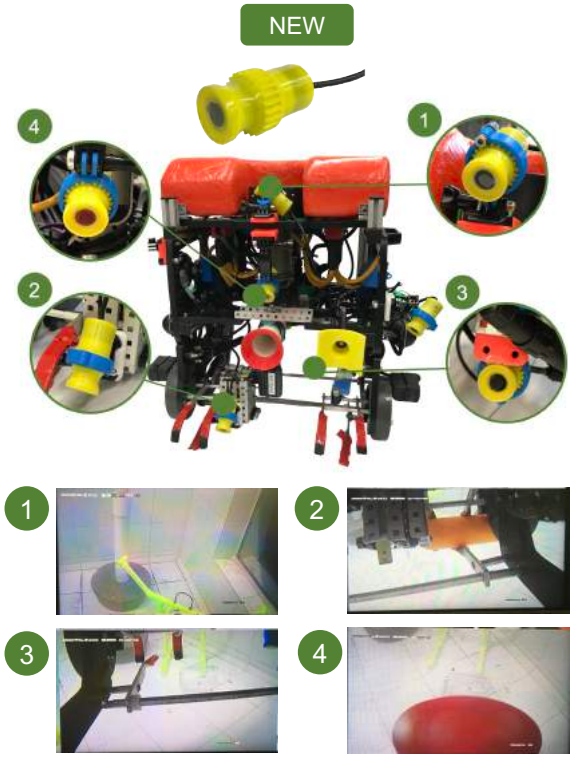


Figure 20: Video images taken by different cameras

We also made covers to protect our cameras, since they are attached to ***Eta***'s exterior and are prone to scratches and mechanical damage. Our first try with 3D-printing was a little less than successful. 3D-printing enabled us to customize its shape so that it fit snuggly at minimum weight, but PLA's water absorbing properties led to the leakage of moisture into the cameras, fogging them up. This was resolved by first making the casings at least 4mm thick, and then vacuuming the cameras' cavities in an approximately 0.2-0.7mm layer of epoxy, so that no air nor water penetrated its interiors. Permanently vacuuming the cameras in epoxy also help fix their positions, so that bumping and other means of contact would not cause the cameras to lose their focus.

Manipulator

Eta is equipped with two manipulators which open and close in a clamping motion. The manipulators are powered by turntable bearing kits, and are situated on each side of ***Eta***, approximately 25cm apart, which makes it ideal for transporting long cylindrical items.

Each manipulator consists of two upper arms and one lower arm, a lot like the talons of an eagle. Each arm is made of bent aluminum bars the lower arm is fixed still to the frame, where the upper arms open and close via the rotational movements of the turntable bearing kit.

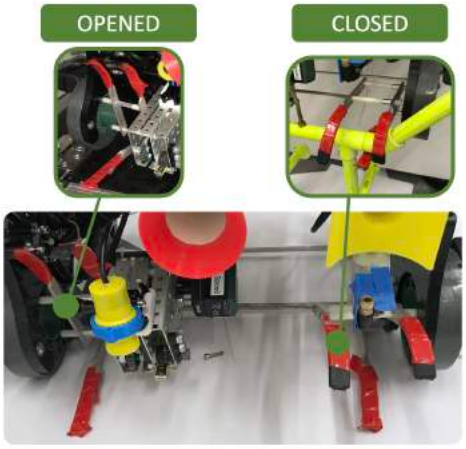


*Figure 21: Photo of **Eta**'s manipulators*

During our local competition, The manipulators were originally made of bare metal rods and placed on the outside of ***Eta***. We then realized they were placed too far apart for gripping shorter props, and that the props rolled loosely around in its grip, which hindered our pace and efficiency while going through missions. We then repositioned our manipulators inside the ROV, and wrapped its arms with electrical duct tape for added friction to secure props in hold.

The structure of the manipulator is extremely simple, composing of only a few components, making it convenient to repair and reduces the chances of malfunctioning.

Ocean Bottom Seismometer (*OBS)*

The OBS is our own design for the ocean bottom seismometer (OBS) required in Task 2.

The OBS is made of several lengths of PVC pipes assembled together by chains, hot-gluing, and fitting parts together. The core of the OBS consists of three parts - the OBS (labelled A in the diagram), the release mechanism (labelled B), and the anchor (labelled C).

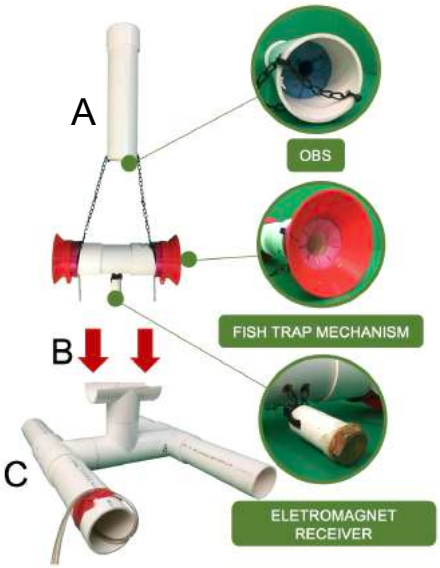


*Figure 22: A diagram of **Eta**'s OBS*

C: The anchor is a matrix of PVC tubes arranged in the shape of an H, all connected by glue. The weight of the anchor comes from the PVC tubes itself, standing at 52x35x18cm, with 3mm thick hollow tubes of a 5.5cm diameter, making it negatively buoyant. The electromagnetic release mechanism is incorporated into the heart of the anchor.

A: The OBS is a horizontal PVC tube chained to a vertical PVC tube. The vertical tube is a PVC tube fitted with a pool noodle, making it positively buoyant. The horizontal tube holds the cable connector with a fish trap locking mechanism. The opening of the tube has flexible inverted-funnel tabs, 3D-printed with Thermoplastic elastomer (TPE), which locks the cable connector firmly. A small piece of metal at the bottom serves as the receiver of the electromagnetic release mechanism. In case of failure, a pin (mechanical release) serves as a backup.

B: The release mechanism works on acoustics. Incorporated into the anchor is an Arduino motherboard, a mic, and an electromagnet. Once the OBS is connected to power, the electromagnet creates a strong magnetic field sticking the OBS receiver and the anchor together. Once a sound with 90 dB or higher is received by the mic, the Arduino program disconnects the power source, de-magnetizing the electromagnet, and releases the OBS. During missions, a car horn simulates the loud noise for activating the release mechanism. It produces a sound of 110 dBs, safely over the 90 dB threshold.

Acoustic release was chosen as our form of release due to its simple means of activation. Since the acoustics only detect the magnitude of the sound but not the sound pattern, in case the car horn fails, the sound can be replaced by other sounds over 90 dB. However, our OBS may also be mistakenly set off by other similar sounds as well. Efforts will be made to limit the sound pattern in future designs.

Acoustic Doppler Velocimeter (ADV)

The ADV is used for marking the placement of the mooring in Task 3. Task 3 requires companies to attach a velocimeter to the mooring line, 10cm above the bottom of the pool.

Our ADV simulates the required velocimeter. It consists of a heavy-duty magnet, attached by a nut and bolt to a GoPro floatation handle, which is also fitted with a backup metal hook.

Figure 23: A photo of ADV in use

Using a magnet is an effective, secure, and convenient way of attaching the ADV accurately to the anchor chain, even preferable over hooks. The magnet attaches itself automatically to the U-bolt of the chain when placed close enough, and saves the time of adjusting and fastening a hook with manipulators. In case of malfunctioning, its backup hook can be used. The ADV is brightly colored, making sure that it is clearly visible through the ROV's cameras even in deep and murky water.

Lift Bag

The lift bags are built to tackle Task 1, which requires the ROV to retrieve two weighted samples, a debris and an engine, to the side of the pool.

Both lift bags are constructed by using zip ties to affix a waterproof bag to one end of a 10 inch length x 2½ inch diameter PVC pipe. The other side of the PVC pipe has an open end, with a hook for attachment to the seabed debris. An airline tubing extending from the tether, bringing air from a grounded air source, inflates the waterproof bag when the lift bag is positioned upwards. When inflated with air, the bag provides lift, sufficient to move weights from the seabed. A bigger bag provides stronger lift force, vice versa.

Figure 24: Photos of Lift Bag (deflated vs. inflated)

PVC pipes were chosen as the main component of the lift bags due to its low cost and light weight. PVC pipes, zip ties, and the waterproof bag are all made of plastic and synthetic fabric, making the assembled item extremely lightweight, reducing greatly the chances of overturning or causing imbalance to ***Eta***. It is also a very simple design, making it very convenient for constructing spares and maintenance purposes. On a practical level, since other mission props are made of PVC too, drivers would likely be more familiar with maneuvering PVC-made tools, hence they do not need extra practice for using the lift bags efficiently.

The lift bag enters the water with its bag side facing down, to prevent the air from being trapped (Archimedes' Effect) and mistakenly inflating the lift bag, causing the ROV to float, and is only turned the right side up when in use.

ScreenRuler

ScreenRuler is an application used for calculating the distance from the base to the ADV in Task 3. The application connects all cameras installed on ***Eta***, which take pictures at many sides and angles to measure the distance in front of or under the ROV.

It is a computerized program operated on our Surface Pro notebook. It calculates distance by comparing the proportions of the same object in two different images. ScreenRuler tracks specific objects with deep learning modules. It is trained to automatically discover objects in murky water and even when visibility is low, which helps us increase measurement accuracy.

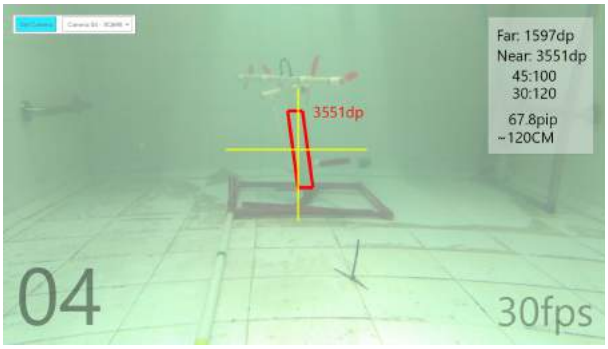


Figure 25: A screen capture of ScreenRuler's interface

When the application is activated, one near shot is first taken, either by bringing the object up close or moving the ROV near the object. The user has to frame the object in the captured image and enter its dimensions. Once framed, no matter where the object is repositioned, the app will track the same specific side of the object and autolocate the tracked object. After that, the program calculates distance based on the proportions of the long shot compared to the close shot, as displayed in figure 25. In case of failure, a heavy-duty measuring tape with a hook can be operated manually as a backup. The measuring tape is stretched and kept by a turntable bearing kit, and it is positioned near ***Eta***'s right manipulator.

Determine Zone

Determine Zone' is an application designed by ourselves for determining the search zone for the wreckage in Task One. We can easily find the search zone by inputting value such as the ascent rate and airspeed on descent etc. The application can automatically calculate the ascent vector, descent vector and wind vector. It can also draw paths on the map using canvas technology. The application is an HTML website and can be opened on any computer (our Surface Pro notebook will be used). It is portable and serverless.

A. Company Safety Philosophy

Our company believes that all accidents can be prevented to a certain degree, and that safety is an integral part of our jobs and products.

All CMA employees, regardless of level, embrace the responsibility of promoting safety as our most important value. To achieve said beliefs, CMA Underwater Expert Ltd. has a number of safety procedures. These procedures include devising a rigorous safety checklist, and providing training to those who handle ROVs, or any other equipment in the lab, especially when there are many newcomers this year.

B. Safety Checklist

To ensure proper operation of our vehicles and the safety of our crew, a rigorous checklist must be completed and checked every time when we need to operate the ROV. The checklists are designed for pre-dive (startup power on, launching), on-task (in water, losing communication) and post-dive (returning ROV to surface and deployment) procedures. The presence of at least two operators and the authorization of a senior engineer are needed every time for approving the list and handling the ROV.

Safety Checklist

Staff names (in full): _____ and _____

Date and time: _____

Purpose of handing: _____

Please go through every single line of this safety checklist. Put a tick in the box if the condition is met.

WARNING: Never handle the ROV unless all conditions are met.

Pre-dive (on shore)

1. Start-Up

- ☐ Safety glasses on
- ☐ Ensure the power switches and circuit breakers in Electrical Distribution Control Panel (EDCP) are 'OFF'
- ☐ Tether is properly secured to the EDCP and ROV
- ☐ Power switch is in place
- ☐ All parts attached to ROV are secured
- ☐ Verify thruster shaft seals
- ☐ No conductors incorrectly touching
- ☐ Connectors are fully inserted
- ☐ Make sure the connectors matching with label
- ☐ Protect all spare connectors with dummy plugs
- ☐ Connect the power source to EDCP
- ☐ Ensure the voltmeter display within operation range (12V – 13.8V)

2. Power-On

- ☐ Mission commander call out "Hand Up"
- ☐ Operation technician turn on the power
- ☐ Verify the status of ROV light bar
- ☐ Verify video signal
- ☐ Mission commander call out "ROV Ready"

3. Launch

- ☐ Pilot call out "Ready to operate"
- ☐ Tether tender response "Ready"
- ☐ Pilot call out "Start to operate"

On-task

1. In Water

- ☐ Keep necessary length of tether out for avoiding tripping hazards and tether damage
- ☐ Keep monitoring the voltmeter to check if there are abnormalities (normally 12V and less than 25A)

2. Lost Communication

- ☐ Cycle power switch to reboot ROV
- ☐ If no communication:
  - ☐ Power down ROV
  - ☐ Reconnect with tether

Post-dive

1. ROV Return to Surface

- ☐ Pilot call out "ROV return to surface "
- ☐ Tether tender response "ROV back to surface"
- ☐ Pilot call out "Power down"
- ☐ Operation technician response "Power off"

2. Deployment and teardown phase

- ☐ When ROV operation completed, power off the vehicle and disconnect all cables or plugs.
- ☐ Blow dry the entire vehicle
- ☐ Secure all equipment to deck

In case of emergency, press the EMERGENCY STOP BUTTON on the front side of the Electrical Distribution Control Panel IMMEDIATELY.

	First Staff	Second Staff	Senior Engineer
Signature			
Name in full			
Date and time			

Figure 26: Safety checklist

C. Safety Features of *Eta*

Mechanical Safety

Thrusters on ***Eta*** come with their own safety covers to prevent the blades from contacting other materials, especially protecting human hands. With this year's new IP-20 solid particle protection regulation, all thrusters, regardless of brand, should be protected by shrouds with mesh holes no larger than a child's finger. Seabotix thrusters originally come with their own shrouds, though their holes are presumably larger than acceptable. To further ensure the safety of our thrusters, we have designed an additional shroud through a CAD drawing, and later realized it in PLA (Polylactic Acid) through 3D-printing technology. All moving parts, such as thrusters, are clearly labeled with hazard warning stickers in yellow and black to caution our crew from possible hazards. The manipulator has also been milled during its production process. Sharp edges are a main safety issue threatening our operations. ***Eta***'s frame was designed with rounded edges to avoid any sharp or scratch-prone points. All corners of ***Eta*** are rounded and streamlined.

*Figure 27: No sharp edges on **Eta***

Figure 28: All propellers are shrouded with 3D-printed shrouds

Electrical Safety

A large red emergency stop button is located on our EDCP to cut the power source from the tether to ***Eta*** in case of an emergency situation in our electrical system. We installed a 25A in-line fuse at the beginning of the circuit to prevent the overpowering of the electrical system. A volt-meter and an amp-meter are installed in the control panel to monitor the power source to make sure it stays within a normal range (12V- 13.8V). It makes sure ***Eta*** is in stable operation. In addition, the emergency switch button switches off all communications and power lines shared with ***Eta***, ensuring complete disconnection.

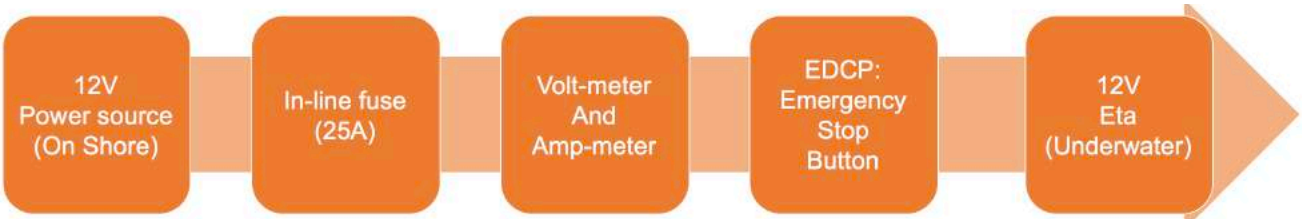


Figure 29: Safety features of the power delivery system

Through observing the input voltage with the volt-meter, automatic shut down by circuit breakers, and manual operation of the emergency stop button, pilots can detect any hazard that can do possible damage to the electrical system. Figure 29 illustrates the safety features of the power delivery system of ***Eta.***

Tether Safety

The safety of our crew members is always of top priority, and equally important would be a consistent, reliable and safe power supply. Without good tether management, the cables inside the tether may break, causing leaks and other hazards. To prevent this from happening, we have set a protocol standardizing tether storage. After each mission, our team members will coil the tether into a reel to reduce inductance and further pressurization to the cable. Transporting the tether in a reel also makes it more portable and time-efficient. This extends tether life, and minimizes the possibility of power leakage on and off shore.

Figure 30:
Paul CHOW coiling *the tether into a reel*
(by Beth AU)

Logistic Safety

During transportation, we can quickly uninstall the core components such as the manipulator, buoyancy board, or subfame, to ensure that they remain intact and functional during missions. In one of our previous competitions, we transported the ROV in one piece. Parts emerged broken or loosened after delivery. From then onwards, components are now separately stored from the ROV and protected with bubble wrap during transport.

D. Training

To ensure that the operating procedures of the ROVs and equipment in the lab are taught to newcomers, returning members would hold a 4-day course for the entire crew, which contains 10 lessons in total (each lesson lasting 45 minutes) before one can actually operate the ROVs and other equipment.

Assessments and exercises are given to the attendees, who are required to do a brief presentation to show their understanding by presenting the operating procedures of certain devices or components. A safety test is conducted to raise their awareness and understanding of safety. Newcomers are also reminded to adhere to safety protocols and complete safety checklists when operating ***Eta***, and must be accompanied by mentors or seniors the first few times. With proper training and standard tests, we can guarantee that our ROVs are controlled and operated by qualified members.

Figure 31:
Newcomers and returning members having a safety training section
(by Louise LO)

A. Company Structure

To provide guidance and clarity on specific human resource issues, a formal organizational structure is implemented. By laying out a clear company structure, operational efficiency is improved as employees have a clear understanding regarding their hierarchical relationships that govern the workflow of the company. Daily production goals are assigned to employees by the CEO daily during morning meetings with reference to their specific roles and duties, and are subsequently reviewed in the debriefing session at the end of each workday. Figure 32 shows the organizational structure of CMA Underwater Expert Ltd.

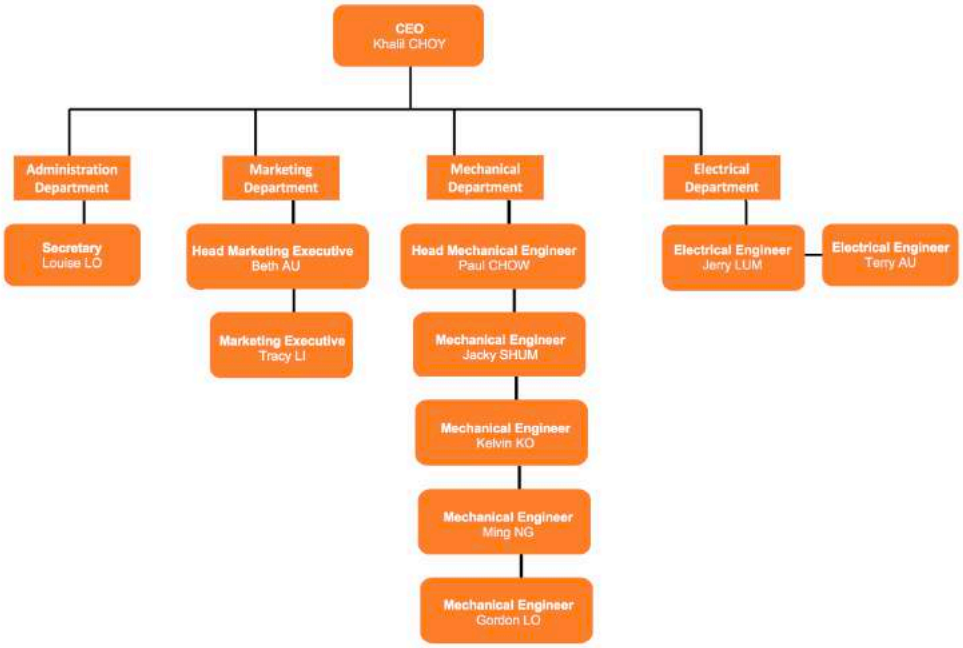


Figure 32: Hierarchy chart of CMA Underwater Expert Ltd.

B. Scheme of Work

To make sure the current schedule status is known to all employees, a well-designed schedule is devised. Department heads are delegated different production deadlines to meet according to their respective responsibilities. The schedule is devised, updated and evaluated by the CEO in weekly meetings and debriefing sessions, for exchanging timely updates and important competition-related news.

Schedule

	2017		2018					
Name	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUNE**
Khalil CHOY *CEO*	Calculate the budget of *Eta*	Research on the terrain, economy, and ecosystem of washing ton state, and on the history and technology of plane wreckages Prepare financial report	Job Safety Analysis Safety Checklist	Write technical documentation Company Safety Review		ROV testing Practice Sales Presentation	Receive comments from regional contest and improve the technical document and marketing display	
Louise LO Secretary			Prepare financial report Write the technical documentation			Practice Sales Presentation	Plan the trip for International ROV competition in Seattle(Air ticket and accommodation)	
Beth AU *Head Marketing Executive*	Get to know ROV design Design safety checklist	Take and edit photos of ROV, mission tool					Recording for ROV testing	Practice the product presentation and product demonstration Prepare documents for transportation Packing all the competition equipment and shipping to competition venue
		Design Logo	Design and edit marketing display					
Tracy, LI *Marketing Executive*		Build and test cameras Test EDCP	Build tether Design and build manipulator Design and build the mission tool: OBS, ADV, Lift Bag, ScreenRuler Build and attach the buoyancy Attaching thrusters on the ROV Make props Waterproof test			Modify the function of components and ROV ROV testing	After the regional contest, improve the performance of all mission tools	
Jacky SHUM Kelvin KO Ming NG Gordon LO *Mechanical Engineer*		Design ROV structure Use Sketchup to create initial design of ROV and manipulator						
Paul CHOW *Head Mechanical Engineer*							After the regional contest, improve the performance of control system, electrical system and tether	
Jerry LUM, Terry AU *Electrical Engineer*		Design and develop the program of control system and electrical system Write GUI				Practice sales presentation		

Figure 33: Yearly schedule

C. Budget

At the beginning of the season, a budget plan was prepared, estimating expenses based on actual expenses from previous years to control cash flow.

Thanks to the support from our school in addition to our regional competition prize money, an income of USD 39,375.30 was obtained to support the MATE ROV competition.

To make ***Eta*** more affordable and hit target costs, certain components from our previous ROVs were reused, with a total value of USD 4,469.11. This year, we spent USD 27,997.56 for purchasing new parts and other expenses with a surplus of USD 6,908.63.

	USD
Total Incomes	39,375.30
Total Expenses	32,466.67
Surplus	**6,908.63**

Figure 34: Summary of income and expenses from Sep 2017 to Jun 2018

The CMA Underwater Expert team, together with its supervisors, mentors and our crew, had altogether contributed an approximate 3,500 hours for planning, designing, building and testing in this project since September 2017. The financial report is shown on the right side.

Financial Report for Eta (September 2017 - June 2018)

Income	Description	Type	Qty	Cost Per Item (USD)	Total Cost (USD)
Income					
School Funding	For Regional Competition from CMA Secondary School	Donated	N/A	N/A	6,510
Prize Money	IET/MATE Hong Kong Underwater Robot Challenge 2018	Sponsored	N/A	N/A	625
School Funding	For International Competition from CMA Secondary School	Donated	N/A	N/A	32,240
				Total of Income	39,375.30
Expenditure					
Expenditure	Desription	Type	Qty	Cost Per Item (USD)	Total Cost (USD)
ROV Parts					
Frame: High-density polyethylene (HDPE)	Re-used from 2017 ROV (Zeta)	Re-used	N/A	N/A	385
SeaBotix BTD 150 Thruster	Re-used from 2013 ROV (Beta)	Re-used	4	769.23	3,076.92
Tether Cabling	15m, Re-used from 2017 ROV (Zeta) 1 for 8 AWG Power Cable, 1 for 8 Core Signal Cable, 1 for Wire, 1 for Airline Tubling, 4 for Optical Fiber Cables	Re-used	N/A	N/A	390
Sealed Connector	Used in Motors, Electronic Speed Contollers	Purchased	32	2.56	81.92
120-degree Wide Angles Camera	Front and Back ROV camera	Purchased	8	12.5	100
Styrofoam: 50mm Isopink Extruded Polysyrene Foam Board	3 feet x 6 feet	Purchased	1	40	40
Manipulator Components	Re-used from 2016 ROV (Epsilon) 2 for Turntable Bearing Kit, 2 for Waterproof Motor, Metal Rods	Re-used	N/A	N/A	55
Optical Video Transmitter	Re-used from 2017 ROV (Zeta) Video Signal to Media Convert	Re-used	2	16.03	32.06
Electronic Speed Controllers (ESCs)	/	Purchased	7	19.23	134.61
				Sub-total of ROV Parts	4,295.51
Mission Tools					
Ocean Bottom Seismometer (OBS)	Made by: PVC pipes, Chains, Hot Glue, Arduino Motherboard, Electromagnet	Purchased	N/A	N/A	30
Acoustic Doppler Velocimeter (ADV)	Made by: Heavy-duty Magnet, Hot Glue, GoPro Floatation Handle, Metal Hook	Purchased	N/A	N/A	20
Lift Bag	Made by: PVC pipes, Waterproof bag, Metal Hook	Purchased	N/A	N/A	10
				Sub-total of ROV Parts	30.00
Electrical Distribution Control Panel (EDCP)					
VEX Contoroller Kit	Re-used from 2012 ROV (Alpha)	Re-used	1	205.13	205.13
Optical Video Receiver	Re-used from 2017 ROV (Zeta) Video Signal to Media Convert	Re-used	2	16.03	32.06
Flight Case	26" (L) x 24" (W) x 39" (H) For Building the Control Panel	Purchased	1	187.5	187.5
Tether Reel	Storage of Tether	Purchased	1	12.5	12.5
24" Monitor	For Building the Control Panel	Purchased	1	100	100
8-channel DVR	For Building the Control Panel Re-used from 2017 ROV (Zeta)	Re-used	1	250	250
Optical Video Transceiver	For Building the Control Panel Re-used from 2017 ROV (Zeta)	Re-used	1	25	25
220V AC to 12V DC Converter	Re-used from 2017 ROV (Zeta)	Re-used	1	12.82	12.82
Amp Meter	50A Max, Re-used from 2015 ROV (Delta)	Re-used	1	2.56	2.56
Volt Meter	100V Max, Re-used from 2015	Re-used	1	2.56	2.56
Miscellancous Components	Switches, Wires, Connentors	Purchased	1	12.82	12.82
				Sub-total of EDCP	842.95
Others					
Comsumables	Sand Paper, Glue, Drill Bits, Epoxy, Solder, Saw Blades, Zip Ties	Purchased	N/A	N/A	128.21
PVC Tubes	Building prop	Purchased	N/A	N/A	125
3D printer Filament: 1kg PLA	Used in Camera, ESCs, Optical Fiber and Styrofoam	Purchased	5	3.5	17.5
Printing	Marketing Display	Purchased	N/A	N/A	30
Transporation: Regional Competition	Renting Coach for 2 days (Round Trip)	Purchased	2	212.5	425
Transporation: Internatioanl Competition	Renting Coach from School to Hong Kong Airport (Round Trip)	Purchased	2	187.5	375
Transporation: Internatioanl Competition	Air Fare from Hong Kong to Seattle (Round Trip)	Purchased	13	950	12,350
Transporation: Internatioanl Competition	Renting Coach for 3 days (10 hours per day)	Purchased	3	182.5	548
Loading: Internatioanl Competition	Hotels for 8 nights	Purchased	3	2,270	6,810
Logistics: ROV	Courier and other Delivery Cost (Round Trip)	Purchased	N/A	N/A	6,250
Fluid Power Quiz	MATE Competition	Purchased	1	15	15
Regional Registration Fees	IET/MATE Hong Kong Underwater Robot Challenge 2018	Purchased	N/A	N/A	125
MATE Registration Fees	MATE Competition	Purchased	N/A	N/A	100
				Sub-total of Others	27,298.21
				Total Expense of Re-used (ROV) in USD	4,469.11
				Total Expense of Purchased (ROV) in USD	27,997.56
				Total Expenses of Eta in USD	**32,466.67**

*Figure 35: Financial report of **Eta***

A. Challenges

Technical

This year, one of our main obstacles was devising a suitable shroud for ***Eta***. With the new IP-20 solid particle protection regulation, we had to design and construct new shrouds with holes smaller than 12.5mm from scrap. The shrouds were first designed as a CAD drawing, and later realized by printing them in the material PLA(Polylactic Acid) through 3D-printing technology.

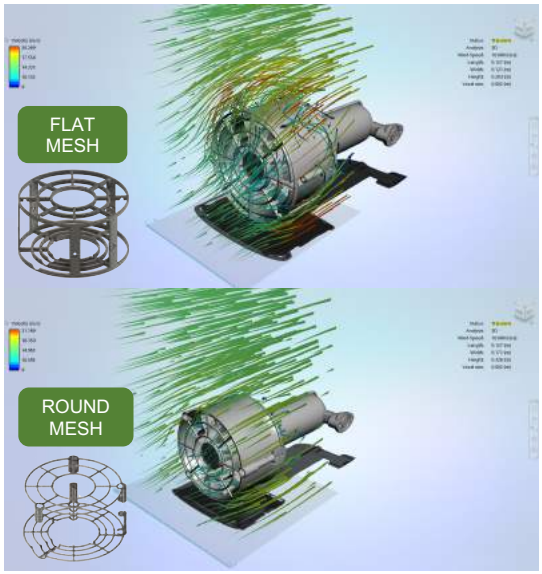


Figure 36: difference in water resistance of rounded meshes and flat meshes

Throughout the design process, the factor concerning us most was how to balance shroud diameter and thrust power. The finer the shroud mesh, the better it would be, but thruster speed would then be compromised. Calculations had to be made to determine to what extent the shroud increased water resistance when the thrusters were put in use, and how it affected the overall speed, power, and weight-carrying capacity of ***Eta***.

The process itself is tedious in a way, as simulation processes had to be done before the product of 3D-printing resembled the results we wanted. To minimise water resistance, the shroud thickness and diameter had to be very fine and thin, and broke easily when we were removing the final product from the supports printed along with it. The shrouds are also assembled only by small plastic screws. To improve the design, it would be better to convert the screw openings to clasps or auto-locking mechanisms to make the connections more sturdy.

Non-technical

With a few key senior members graduated while others are preoccupied with their final-year projects this year, our team had to enlist new members swiftly with only 2 returning members. One main challenge ahead is the change of new blood. Though there were sufficient coaching staff and mentors who return to provide guidance, it still remains a challenge that many of the functioning staff lack the experience and ability to handle a large-scaled multi-area project in terms time of management, utilizing their skill sets, and attending meticulously to details.

To combat the problem, an operational handbook and online open-source learning platform was pioneered to ensure the continuity of our team. On top of hands-on training laid out for our novices, our mentors also recommended additional readings, such as journals on thruster dynamics. Extra material was shared on an open platform to encourage team members to constantly explore technological updates and seek their own learning preferences.

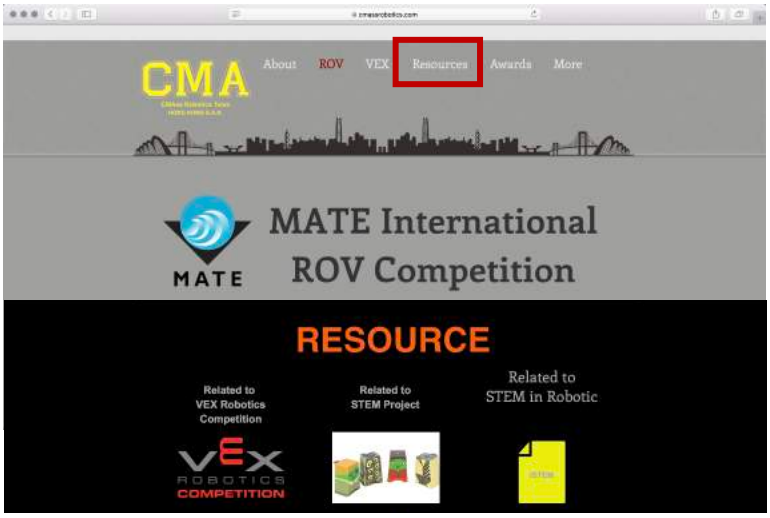


Figure 37: Open-source learning platform at www.cmassrobotics.com

Our team has always valued team bonding, as a collaborative team environment creates better drive and communication. To make the new team even more closely-knit, we organized team bonding activities, such as mini ROV workshops, movie days, and regular lunch gatherings to get to know each other better. Over the past few months, a strong relationship was fortified among all of us and we are like family.

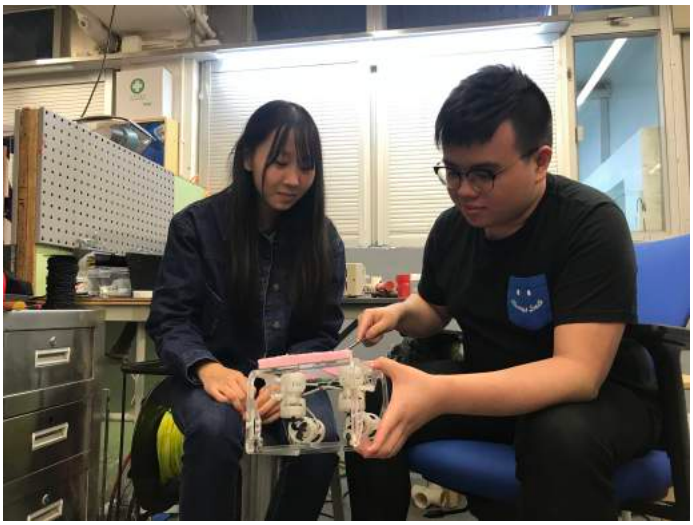


Figure 38: Mentor and mentee building a mini ROV together (by Beth AU)

B. Troubleshooting

Troubleshooting is essential to the success of ***Eta***. Our vehicle has undergone hours of water-testing and dry-runs, while all processes are closely supervised to ensure the functionality of the machine.

Problems encountered during the test are solved with our own Troubleshooting Approach. It begins with verifying whether problem exists, or if it is just an operational error. Once verified, we then identify the problem and its cause, followed up with an appropriate diagnosis. A quick fix or contingency design will be employed depending on the level of damage. The vehicle is further verified to check if there are any other potential problems and to ensure its reliability. The last step of our approach is to follow up, record the problem, and prevent the same problem from happening again.

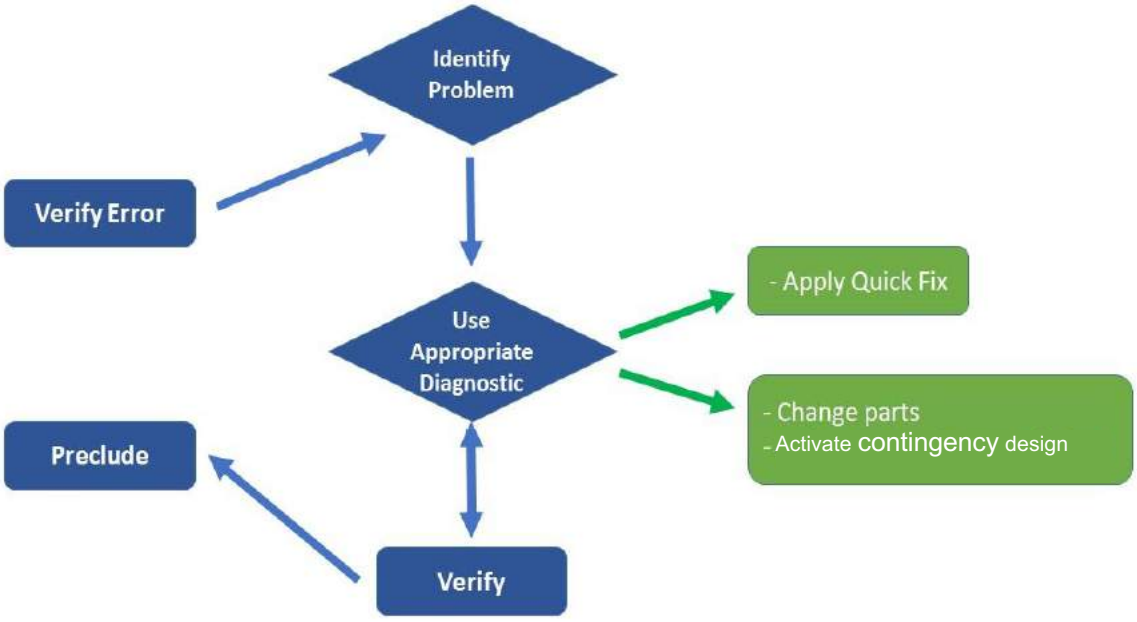


Figure 39: The troubleshooting approach of CMA Underwater Expert Ltd.

C. Lesson Learnt

While working on the project, we have obtained and improved upon a variety of skills in mechanics, engineering, electronics and programming as well as teamwork. It provides invaluable experience that in no way could be taught in class.

Technical

With the large number of newcomers, we focused on helping members experiment on and practice their newly learnt technical skills. This year, we mainly focused on two fabrication skills - cutting material through CNC milling and experimenting with different materials in 3D-printing.

We used a Computer numerical control (CNC) Milling machine to shape ***Eta***'s frame from High-density polyethylene (HDPE). CNC cut designs are more detailed and have a smoother finishing, thus it is a better means of manufacturing hard, flat surfaces for use.

We also tried going to futhter extents of utilizing 3D-printing. A suitable choice of material is vital to the final products' efficiency and result, hence we used an array of different materials to fabricate different parts of our mision tools. For regular and rigid props, such as the funnel opening of our OBS and the arms of our manipulator, used (PLA) filament. For parts that provided protection and needed added strength, such as the new shrouds on our thrusters, we used PLA plus, a more rigid and stronger material. For parts that needed a bit more flexibility, such as the fish trap locking mechanism in our OBS, a flexible filament named Thermoplastic elastomer (TPE) was used. All designs were first drafted as Computer-aided Design (CAD) diagrams, and then fabricated through a 3D-printing machine.

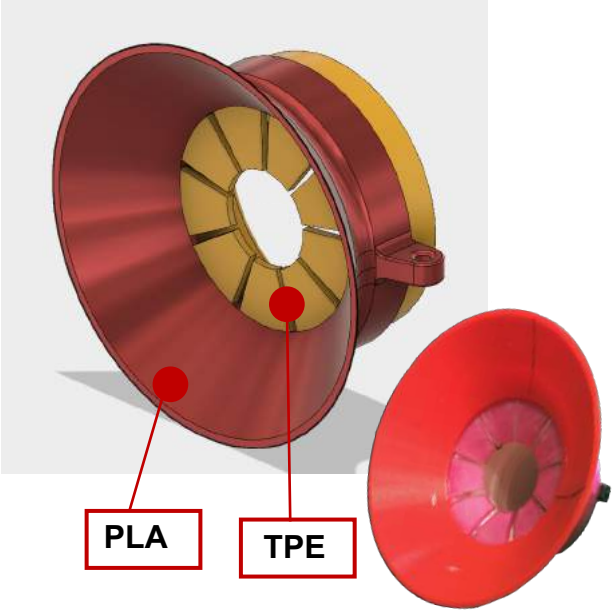


Figure 40: A CAD diagram showing how different materials are used for the funnel and fish trap mechanism of the OBS

Interpersonal

We have further reinforced our strong team spirit and interpersonal skills in this journey. The sophisticated creation of ***Eta*** required countless time and effort. Communication and cooperation between teammates is indispensable at every stage of production. We learned to accept others' opinions and listen to others' ideas. Moreover, we have learnt to give positive encouragement as well as give practical and objective comments in order to perfect our products. When our mechanical engineer, Ming NG, was working on the design of ***Eta***, he listened to the advice of others, while those who were giving comments avoided any sharp language. We sought advice from our supervisors and thought of alternatives whenever we faced difficulties. Throughout the designing process, we created a more and more harmonious working environment where everyone was willing to be productive and respect each other.

*Figure 41: Ming NG lowering **Eta** into our test pool (by Beth AU)*

D. Future Improvement

Although it was such a great achievement improving and innovating new tools for ***Eta***, we believe that improvements can always be made.

Figure 42: Mentoring scheme for learning poolside set up
(by Beth AU)

Our team has room for improvement in terms of management and human resources. Our biggest challenge this year was dealing with too many new members, and we foresee that the change of blood will always remain an obstacle we have to tackle. We hope to devise a training curriculum to help newcomers learn as much as possible about our technical and management level operations. A possible option would be developing a set of e-learning materials or a company manual, which encourages members to do independent learning autonomously and efficiently. However, one-way learning is not always the best form of learning.

A more interactive and humanistic approach would be adopting a mentoring scheme. Given that we have a large mentor-to-mentee ratio, it is possible to pair newcomers up with mentors, so the newcomers will be able to get hands-on experience when working with or observing how their mentors work. In addition, each mentor has their own expertise and specific skill sets, hence mentees will be able to shed valuable insight. We hope that in time, such a mentoring scheme will become normalized into CMA's culture, and that mentors and mentees will form a close-knit community.

E. Reflection

Khali CHOY, CEO (Grade 11)

I would like to express great gratitude to MATE and CMA Robotics Team for providing me with a platform developing a lot of my generic skills and traits. This is my first year participating in MATE ROV, which is also our company's first year with a a very low count of senior members, as they had all graduated after MATE ROV 2017. It did intimidate me at first. With a six-year record of participating in the MATE ROV International Championships, I didn't want to become the first CEO who did not lead the team into the finals. I was eventually successful in converting my fear and pressure into passion and assurance, and I did my best to learn as diligently as possible from my seniors and mentors.

Figure 43:
Khalil posing with our Vice-Principal at the Hong Kong regional contest
(by Beth AU)

After committing myself to the competition, I awoke to the fact that MATE ROV is not solely a project of robotics, but also of life skills, collaboration between teammates and mentors, language, and self expression. Creating an ROV enabled me to exceed my own limits both in terms of mental growth and hands-on skills. Careless as I used to be, I learnt to attend details, such as waterproofing ***Eta***, a seemingly small step which often puts the entire project at stake. Being a CEO, I had to hold meetings, work around hectic schedules, and make crucial decisions, and even settle disputes.

In the very beginning, I was extremely unaccustomed to being a key player in so many processes, but with out-of-their-way support from my teammates and mentors, we developed a close-knit community, which was the main factor which made things work. Words cannot express my gratitude, and I cannot express how thankful I am, to have worked with a team of fighters, leaders, and friends.

Louise Lo, Secretary (Grade 11)

This is my second year participating in the MATE ROV competition, and this has allowed me to see things from a different perspective. With many new recruits and a change of positions among old members, there has been significant change in both our responsibilities and our roles, but this has not faltered our relationship nor our efficiency. Last year, I was in charge of a vast majority of administrative and report-related duties. I had to communicate with a lot of teammates regarding scheduling, moderating, and report information. There were often disputes, some of our compromises even required the assistance of our mentors.

With a year of experience backing me up, I reflected on last year's problems, and I focused on managing my interpersonal relationships better. I have become more humanistic and meticulous when solving problems, and I am now more sensitive to my team members' needs and feelings.

It's been a fruitful experience for me, not only in terms of enriching my knowledge about robotics, but more importantly, my capabilities as a leader and coordinator.

Figure 44: Louise LO making amendments to our technical report (by Beth AU)

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Figure 45: Logos of the acknowledged parties