CMA UNDERWATER EXPERT LTD.

ZETA

TECHNICAL DOCUMENTATION

2017 MATE International ROV Competition

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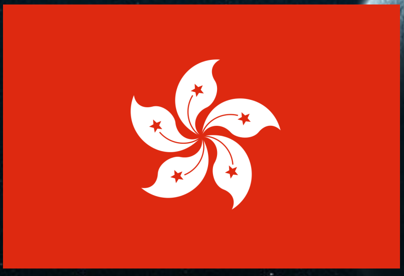

HONG KONG

CMA SECONDARY SCHOOL, CMASS ROBOTICS TEAM

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Abstract

CMA Underwater Expert Ltd. is proud to present this year's re-innovated Remotely Operated Vehicle (ROV) - ***Zeta***. From large-scale underwater construction processes of the Hyperloop transport system, to entertainment facility maintenance, to dealing with water pollution, our ROV hopes to make the port of Long Beach healthier and safer for its citizens and waters.

With more than 9 years of experience in ROV research and development, we aspire to outdo our old designs every year in terms of size, efficiency, durability, and stability. ***Zeta*** is designed for handling a wide array of underwater works. It moulds and builds concrete parts of the Hyperloop system, and transports and changes equipment used in light-synchronized water shows. ***Zeta*** is also capable of extracting, recognizing, and marking various types of pollutants.

Standing at 330mm(W) x 370mm(L) x 375mm(H) and weighing 10kg with an interchangeable and detachable tool compartment, its stability is maintained through utilizing 6 SeaBotix thrusters to enable horizontal and vertical movement. Choosing High Density Polyethylene (HDPE) greatly reduces weight. An optical fiber transmission system is used to ensure best signal reception and better tether management. An omni-purpose manipulator along with its detachable mechanism enhances its functionality, portability and versatility, and makes ROV maintenance easier and cheaper. For easy launching and logistics, an all-in-one Electrical Distribution Control Panel (EDCP), with a built in 24-inch monitor, is built to connect onboard electronics to send and receive data for communication, observation, and power transmission.

This technical document details the technical components of ***Zeta***, the latest ROV designed and manufactured by CMA Underwater Expert Ltd.

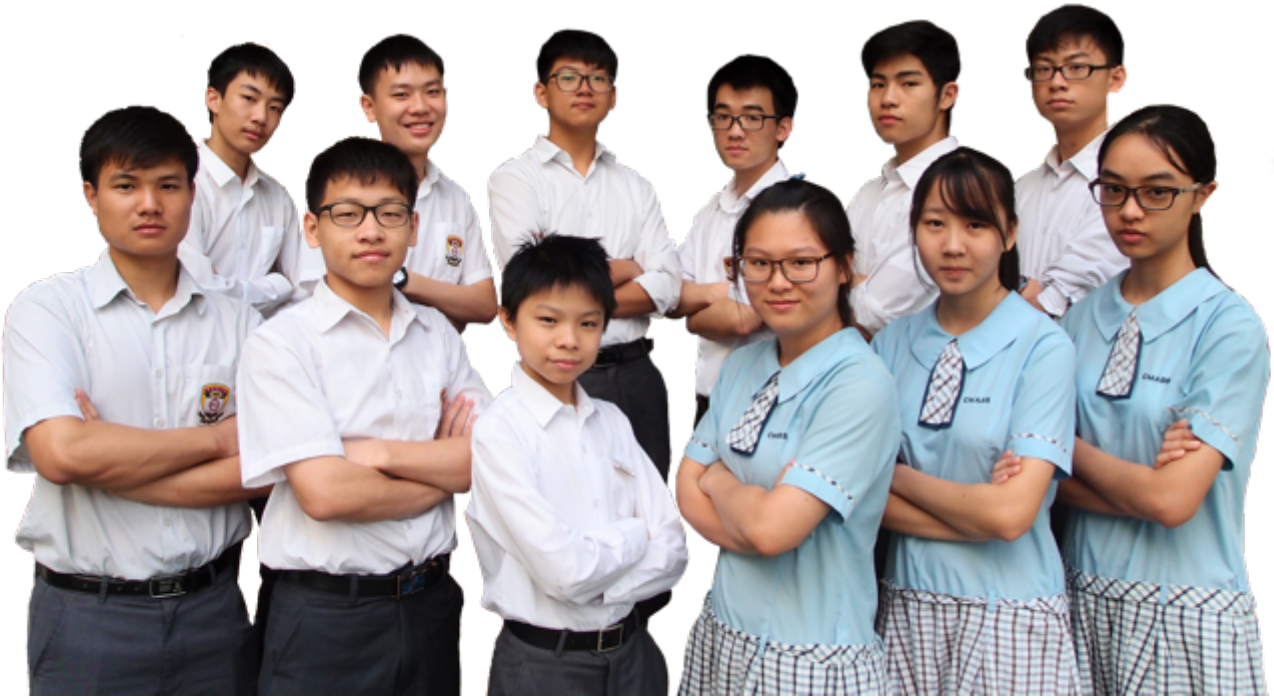


Figure 1: Team photo
(Top left) Kelvin KO, Jayden CHAN, Anson ZHAO, Devin LAI, Anderson ZENG, Krios LIANG
(Bottom left) Paul CHOW, Yang XIA, Jerry LUM, Amber LIN, Louise LO, Beth AU

Design Rationale 04

A. Aim

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

The primary objective is to build an integrated underwater robot which is comprehensive, yet miniature and lightweight. The ROV's size is scored by fitting measurement rings over the machine - ***Zeta*** targets at meeting its size score by fitting into the smallest ring, which measures 48cm in diameter.

The second objective is to devise a good troubleshooting mechanism, as comprehensive troubleshooting is the key to making a ROV safe and reliable. ***Zeta***'s manipulator is a heavy-duty payload tool, and the most frequently used. The troubleshooting mechanism will be targeted at monitoring ***Zeta***'s manipulator.

B. Design Process

In pursuit of creating an ROV which is compatible with our company's standard and the requirement of MATE 2017, 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 also arranged for drivers for better preparation in the international competition.

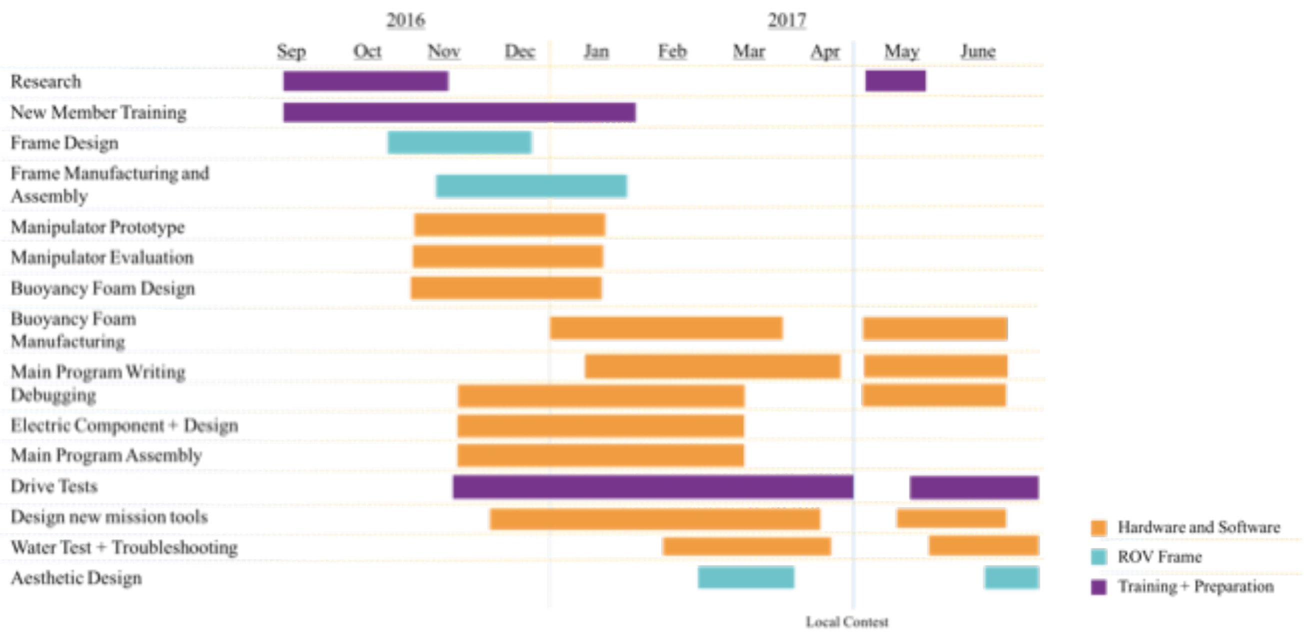


Figure 2: The development timeline

C. Design Philosophy

In order to produce the most efficient ROV for customers with various needs, the focus is placed on versatility as ***Zeta***'s design philosophy . ***Zeta*** 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, one 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, one can even opt to forgo its subframe, further reducing ***Zeta***'s weight.

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

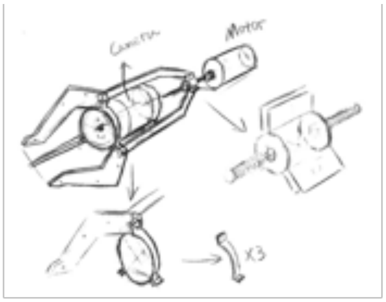


Figure 3: Concept drawing of manipulator

Figure 4: Concept drawing

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.

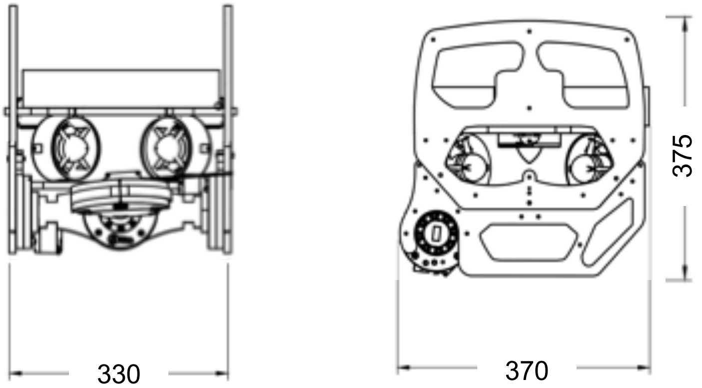


Figure 5: Final design of ***Zeta***

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.

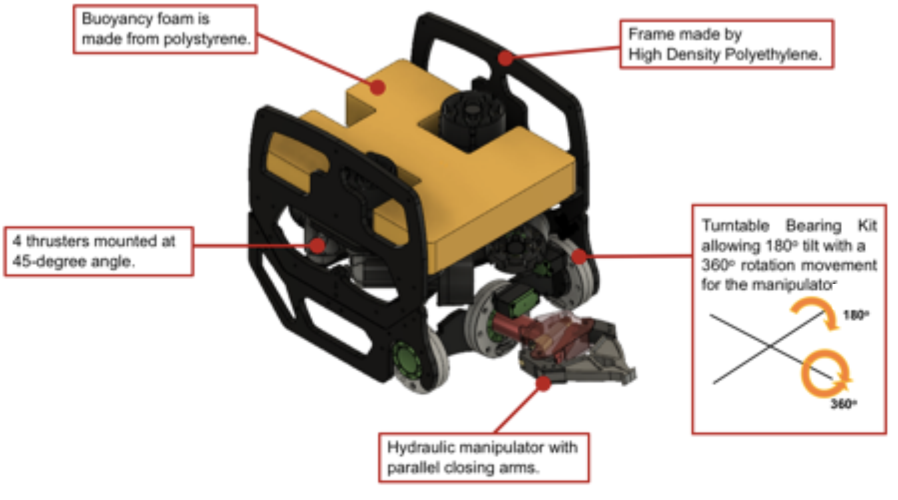
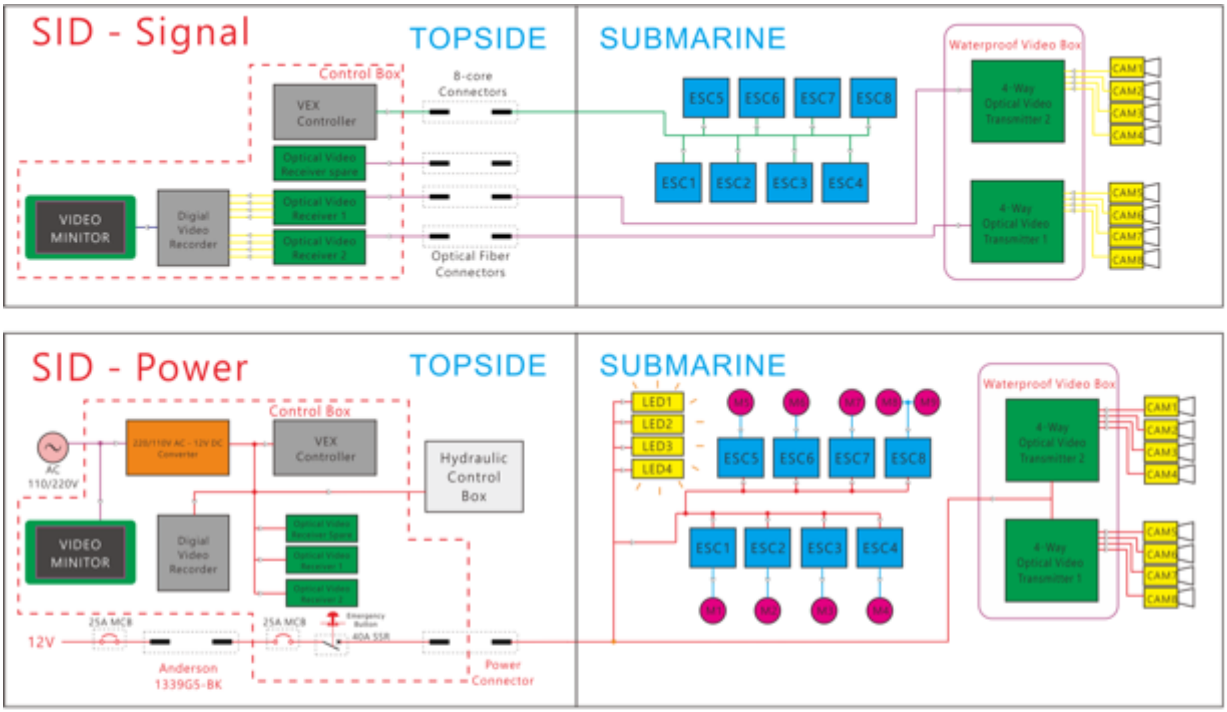
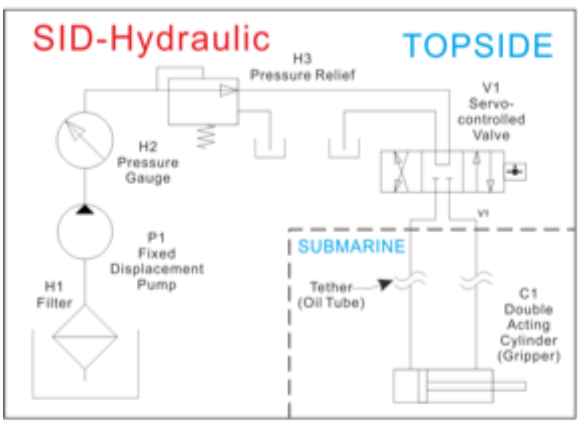


Figure 6: CAD model of ***Zeta***

E. System Interconnection Diagram (SID)





Fuse Calculation			
Component	Power (W)	QTY	Total(W)
Seabotix BTD-150 (M1-M4,M8,M9)	35	4	140
Camera (CAM1-CAM8)	0.5	8	4
Optical Video Transmitter	12	2	24
LED (LED1 - LED3)	1	3	3
Gripper (M5,M6,M7)	20	1	20
		Total	191
Maximum current A(max) = Total Power / Voltage			
A(max) = 191/12=15.9A			
Fuse value =15.9*1.5=23.85->Use 25 A fuse			

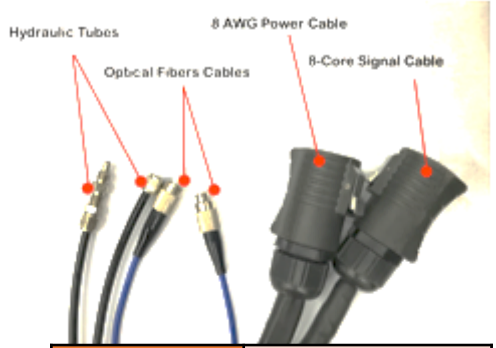
*Figure 7: SID of **Zeta***

Using optical fibers to transmit camera signals conducively reduces interference as well as keeps ***Zeta*** 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) is used to rapidly disconnect the power provided to the ROV in case of emergency.

F. Tether

The tether of ***Zeta*** is 15 meters long consisting of two 8 AWG power cables, two optical fibers cables, two 8 core-signal cables and 2 hydraulic tubes. The 2 power cable is used to provide power to ***Zeta***, while one 8 core-signal cable is used for communication and the other serves as a backup for emergencies. Since we are using eight digital cameras, two optical fibers are used to handle camera signals and 2 hydraulic tubes control the manipulator. A wire prevent the crack of tether.



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

*Figure 8: Tether specifics of **Zeta***

In previous years, we had been participating in Explorer Class all along, where a voltage of 48V was provided. The power consumption of our past ROVs were made based on 48V power provision, thus we had to make major modifications to account for the threefold voltage drop from 48V to 12V. The thin silicon power cable we used in previous years does not fulfil this year's requirements, since the amount of power it conducts is insufficient for our thrusters with a voltage drop from 12V to 9V, making our ROV unstable during operation. We have then opted for an 8 AWG power cable for stable power provision.

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.

G. Frame

To reduce the weight and size of the ROV without sacrificing strength and durability, ***Zeta***'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 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 ***Zeta***, as its dependence on a large float or ballast is greatly reduced, making ***Zeta*** 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 ***Zeta***'s frame.

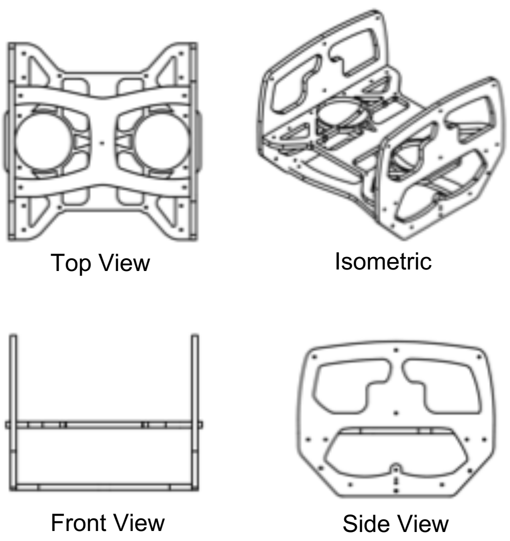


*Figure 9: Overview of **Zeta**' s frame*

There are also a few other distinctive characteristics of Zeta's frame. The corners of Zeta are rounded as a safety measure, to ensure that the ROV is safe to handle. Two different brands of thrusters have been purchased, and are interchangeably used depending on different needs. The hole for the thrusters are universal, fitting both SeaBotix and BlueRobotics thrusters, making the frame compatible with different parts.

The open frame of ***Zeta*** provides minimal obstruction and has enough space for the installation of the electronic speed controllers, optical fiber receivers, and thrusters. All fixed electrical components have been placed in the main frame for convenient electrical connection from the tether. Apart from connecting or installation of the components, a separate subframe enables the easy removal of malfunctioning components. The subframe houses the manipulator, an actuator, and a turntable bearing kit.

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, ***Zeta***, comes to place. Our robust ***Zeta*** is now proved to be small but precise, simple but powerful, and able to work efficiently with variable water flow. Once the design is finalized, it will be sent to a manufacturer to be milled into desired shape to ensure better quality of the structure.

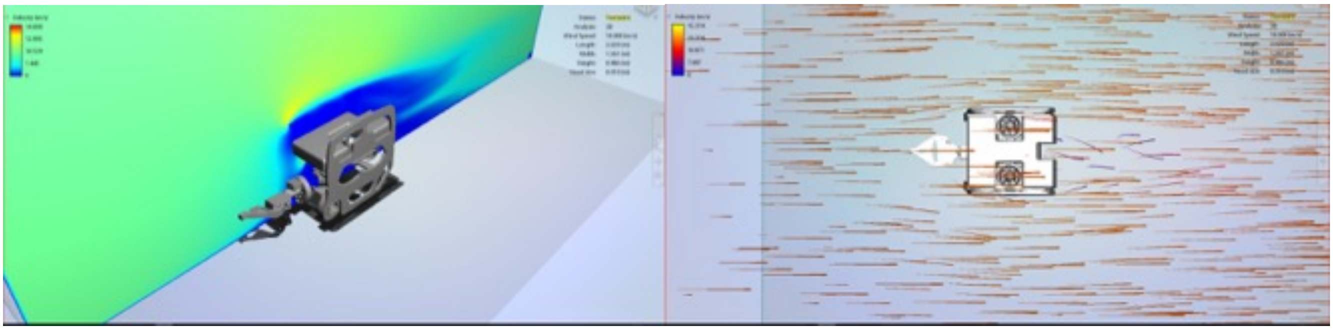


*Figure 10: Flow test simulation of **Zeta***

The most efficient feature of the frame of ***Zeta*** is its easily detachable compartment, which allows effective installation and maintenance. It can be separated into two sections within five seconds by detaching or disconnecting any other components such as buoyancy board and clip by removing a few screws. This feature enables the clear monitoring of all components during mission and convenient repairing within a short time. The quickly detachable mechanism is designed for easy shipping, and to prevent any possible damage caused by logistical issues. Also, all sharp corners of the frame has been protected with plastic covers to prevent them from doing harm to anyone. During transportation, we can quickly uninstall the core components such as manipulator, buoyancy board or clip to ensure that they can remain intact and functional for mission. These components will be separately stored from the ROV with bubble wrap. ***Zeta*** is separated into 2 main sections: The Manipulator Section and The Electrical Section. The Electrical Section houses electronic speed controllers, optical fiber receivers, and thrusters. The Manipulator Section houses 3 turntable bearing kits with 1 manipulator.

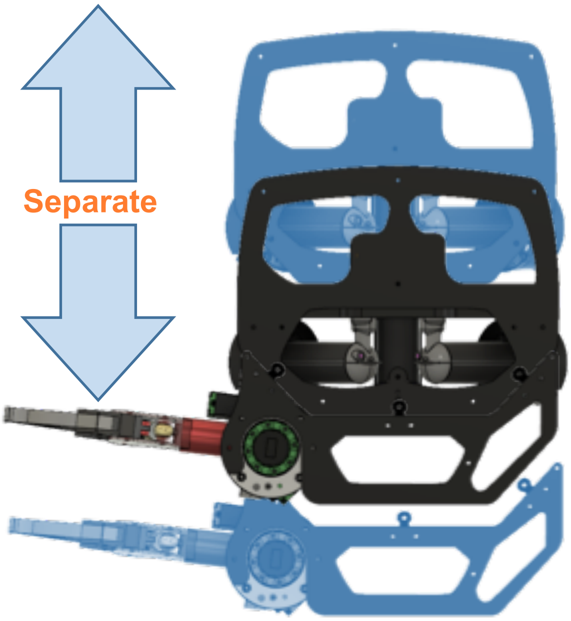


*Figure 11: **Zeta**'s quickly detachable subframe*

H. Electrical Distribution Control Panel (EDCP)

The Control Panel is the main control system for Zeta 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 three optical fiber transmitters which are installed on ***Zeta***. One optical fiber transmitter can only transmit four camera signals; thus 3 optical transmitters are installed - two send a total of eight camera signals to the optical fiber receivers in the Control Panel, one is an extra, which is compatible with our backup ROV. The three optical fiber receivers transfer 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. 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. In addition, an Intel NUC Kit PC operated with Windows 10, is installed for data analysis, software troubleshooting and streaming to the internet without having to carry any other laptops.

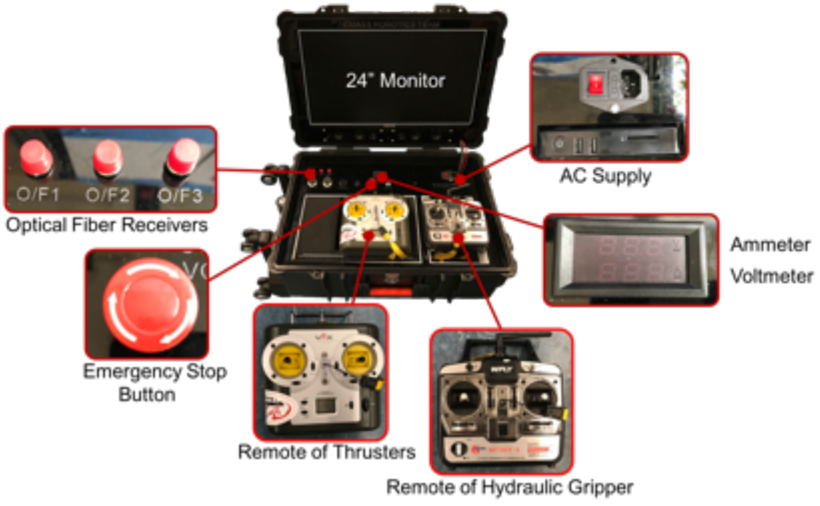


Figure 12: Features of EDCP

I. VEX Controller Kit

The ROV is controlled by two VEX Controller Kits, each VEX Controller Kit controlling six Electronic Speed Controller boxes, which in turn control the motions of ***Zeta*** since we are using 6 thrusters for movement and three turntable bearing kits for the manipulator. Apart from controlling the motion of ***Zeta***, another VEX Controller Kit controls three Electronic Speed Controllers boxes, which controls the performance of the manipulator and the turntable bearing kit. These control system consists of two 750MHz RF transmitters and one receiver remote control with two radio transmitter units and compatible receiver units. 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 VEX controller joysticks can be widely found from remote-controlled toys and models, thus the resources spent on pilot training for the operation of ROVs is greatly lessened.

J. Electronic Speed Controllers (ESCs)

Six SeaBotix thrusters, together with the manipulator, actuator and turntable bearing kit are controlled by eight waterproofed 1060 Brushed Electric Speed Controllers (ESCs). These controllers not only provide power to the SeaBotix thrusters, they also connect the VEX Controller and receive signals from it. The ESC can control the moving speed and direction of the thrusters, which can thus provide an effective movement control for the pilot. Weight is of paramount importance when mission requirements are concerned. These controllers are made of acrylic and glass, which is much lighter than the previous iron ESC box.

Figure 13: Comparison of the old and new ESC Box

The brushed ESC is 60A, aiming to control the moving speed and direction of the motor. While the ESC is running, an ongoing sound and LED light beam will be produced, which serves as an indicator for our pilot that the ESCs are functioning normally.

Modification has been made to the ESCs this year. In previous ROVs, the ESCs are were sealed in a waterproofed acrylic plastic box to be cost-efficient. Yet, if one of the ESCs is faulty during the operation, it takes a great deal of time to dismantle the broken ESCs box and make repairs.

This year, we improved the design by individually sealing the ESCs in their own acrylic glass box, creating a mini waterproofed housing for each ESC and filled each with epoxy, and then installing them on ***Zeta***. If one of the ESCs appears to be malfunctioning, we can switch another new mini ESC box with the malfunctioning one more conveniently. This design allows us to conserve time and staff resources and focus on other components to be implemented on ***Zeta***.

K. Thrusters

Zeta is equipped with and operates on six SeaBotix thrusters. Four are mounted at a 45-degree angle to allow cardinal movement at a higher speed with a greater thrust compared to two horizontal thrusters with less thrust and no sideways movement. Four SeaBotix mounted on 45 degrees provides a 2.8x thrust compared to 2x thrust of two parallel SeaBotix. The two remaining thrusters are mounted vertically to provide stronger and quicker levitation for ***Zeta*** in water. Each thruster provides a maximum 5 pounds of thrust forwardly and 4 pounds of thrust reversely. With an operating power of 12VDC and a maximum current at 11.5Amps, it satisfies the needs for Zeta's power requirements. Each thruster is mounted onto the frame with screws screwed into drilled holes. A shroud covers each thruster to minimize debris obstruction, along with a warning sign to remind our team members to take extra care when handling the thrusters.

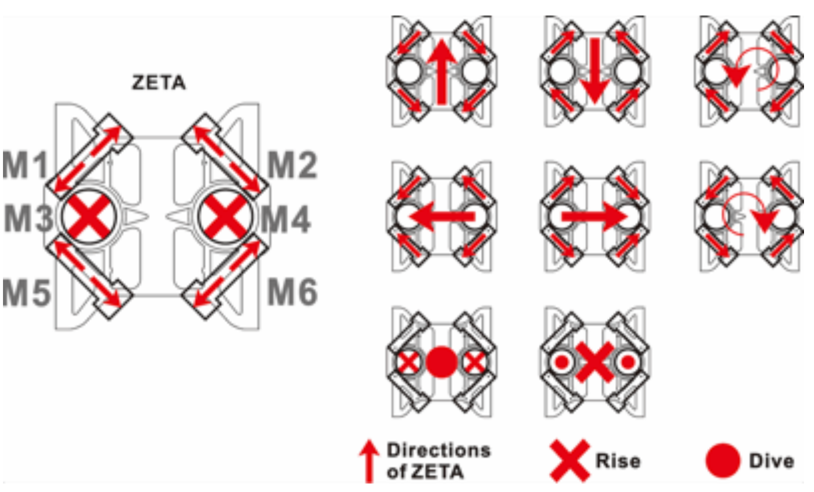


*Figure 14: Explanation of **Zeta**'s propulsion system*

L. Buoyancy

Zeta is fitted with a buoyancy float system specifically designed to neutralize the ROV buoyancy. The buoyancy foam is made from polystyrene as its main material since it is affordable, easy to shape and its peerlessly low density material neutralizes ***Zeta***'s weight in the water. ***Zeta*** 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 ***Zeta***, with all the other components installed, and then testing it in a swimming pool. This testing method calculates buoyancy more accurately than estimating. The weight in water of ***Zeta***, before the addition of the float, was 10kg. ***Zeta*** relies on its H-shaped design buoyancy foam, approximately 300mm x 330mm x 60mm, for a total of 3.89kg of buoyancy, compensating for the vehicle's wet weight. The float pieces are cut by a laser cutter then fiber glassed with bandages and epoxy then 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 hue. The section of tether closest to the ROV was attached with a tether locker to avoid snagging on the ship and threatening the success of the mission.

*Figure 15: The buoyancy of the buoyancy board neutralizes the weight of **Zeta** in water with a total of 3.89kg.*

M. Software Flow

We have chosen the most accommodative software for the movement of ***Zeta***, namely RobotC software, is a graphical programmer which has a great command of software flow, to control the thrusters and manipulator

Before inputting the thruster values, the software double-checks those values to make sure they are within the safety parameters of the thrusters, and then outputs them as PWM (Pulse Width Modulation).

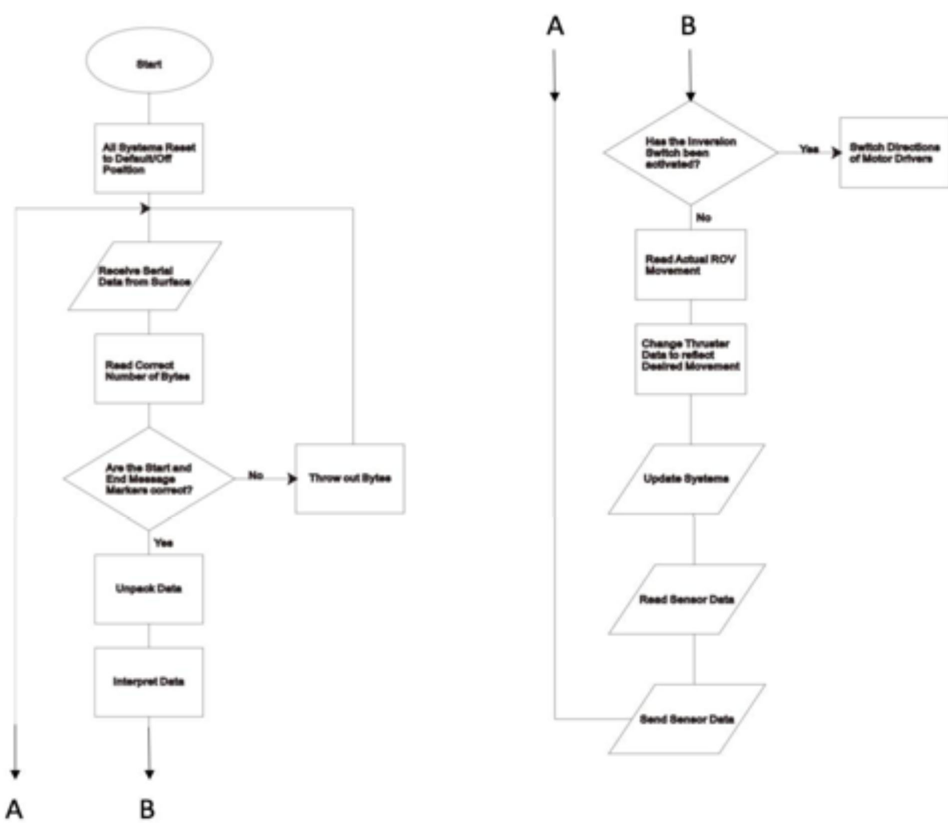


*Figure 16: Program flow of **Zeta**'s control*

N. Mission-Specific

Manipulator

Zeta is equipped with a manipulator which opens and closes in a clamping motion. As opposed to our previous ROV, the manipulator is powered by a hydraulic actuator instead of an electric drive pusher. The change of mechanism benefits ***Zeta*** in terms of reducing both the size and the weight of the manipulator. We have also changed our choice of material from stainless steel (7.9g/cm) to 3D printing, better customizing its shape and further reducing the weight of the manipulator. The use of a hydraulic actuator also shortens the displacement of the manipulator, which improves both its sensitivity and efficiency. The structure of the manipulator is extremely simple. It is composed of only 5 components, which massively increases its reparability, where its simplified structures also greatly reduce the chances of malfunctioning. The hydraulic actuator is connected to the end of one of the arms, where a linkage connects the powered arm to the other arm, providing a synchronous motion upon pushing the actuator (closing the manipulator) and pulling (opening the manipulator). The grip area of the manipulator, which comes into contact with the item being clamped, comes in the shape of an arc, to allow a firmer grip on rounded objects.

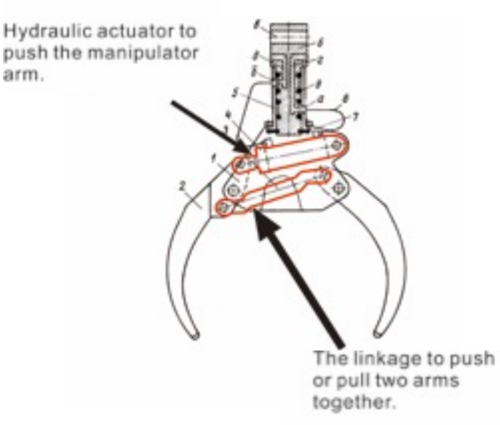


Figure 17: Idea come from http://www.freepatent.ru/patents/2231440

Figure 18: A CAD diagram of the manipulator

A total of 3 turntable bearing kits connect the manipulator to the frame of ***Zeta***. The manipulator is attached to the middle of a HDPE base piece by a turntable bearing kit. A tailor-made waterproof 393 VEX motor is installed on the turntable bearing kit which spins the manipulator (A), allowing both 360° clockwise and anti-clockwise rotation. Two turntable bearing kits attach the base piece to each side of ***Zeta***'s subframe (B & C), positioning the manipulator at the center of the bottom anterior end of ***Zeta***. These two turntable bearing kits turn the base piece, swinging the manipulator in a pendulum-like motion by 180°. This vertical movement stows the manipulator away into the bottom of the frame, greatly improving ***Zeta***'s portability. This mechanism also helps removes the manipulator from the camera's eye if it happens to be blocking the view. This provides better visibility for more precise control.

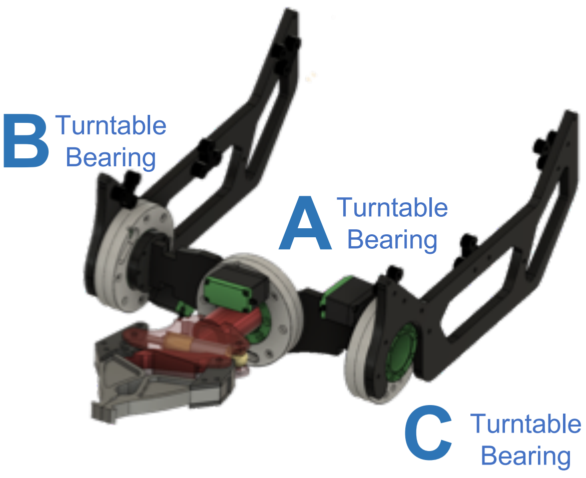


Figure 19: Labelled diagram of manipulator

Elastic Clamp

The Clamp is specially designed to maneuver PVC tubes in Task 1. Four gripping arms, specially shaped for gipping rounded surfaces, extend from the base which is connected to the main frame of ***Zeta***. The whole piece is 3D printed specially with Thermoplastic Elastomer (TPE) printed as this method of production provides a more flexible and refined finished product. When in use, the clamp will spread and close in around the tube, providing a snuggle yet fairly secure grip.

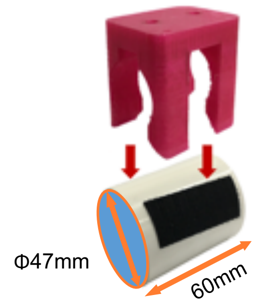


Figure 20: Overview of elastic clamp

Clamp Hand

The Clamp Hand is built to tackle Task 1, which requires the ROV to insert two rebar rods into position in the steel baseplate. A rod passes thought the base plates at the center, to prevent the arms of the clamp from coming too close, but also allowing a sufficient gap to snuggle in a rebar rod when force is applied; two screws are fixed on the exterior of the base plates to stop the clamp arms from opening too wide when it is forced open by the rebar rods. Rubber bands tie the ends of each of the arms together, to increase the tension when clamp picks up the rebar rods. The arms of the clamp are cut in the shape of an arc, to close a better grip around the cylindrical surface of the rods. An acrylic material is chosen over aluminum as its weight may tilt ***Zeta*** down, affecting the buoyancy system and its stability.

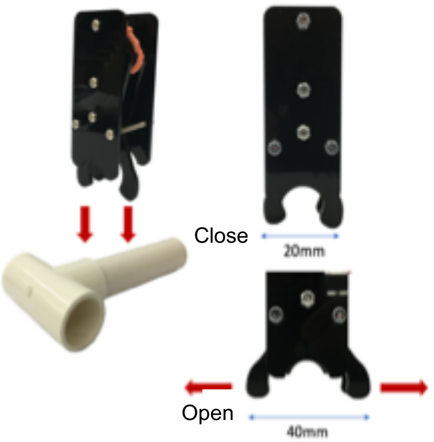


Figure 21: Overview of clamp hand

Buoy

The buoy is used for marking the container with the highest risk in Task 4. It consists of a heavy-duty magnet glued to one end of a PVC pipe for easy gripping, where the other end is connected to a length of rope(length), fastened around a trimmed pool noodle and a floatation buoy as a marker. Using a magnet is an effective, secure, and convenient way of attaching the buoy to the container, even preferable over hooks. The magnet attaches itself automatically to the container when placed close enough, and saves the time required to attach the buoy with manipulators, and the hassle of fastening the buoy.

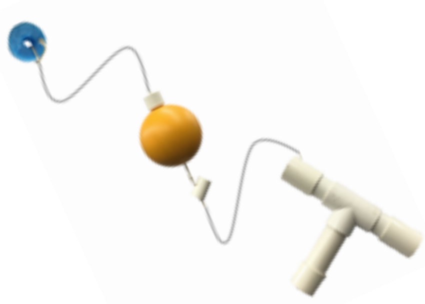


Figure 22:Overview of buoy

Valve Turner

The Valve Turner is designed to tackle Task 2. Task 2 requires the ROV to rotate a cross-shaped valve by 1080º - three whole turns in total. Initially, the manipulator was designed to tackle all tasks including turning the valve, but such a revolving action posed damage to our electric and hydraulic wires due to wear and tear, and increased the risk of tangling wires. A sturdy yet wireless rotation tool was then devised. The valve turner is a sturdy tool in the shape of a tuning fork. It is first designed through a CAD drawing and later realized through 3D-printing technology. It is attached to the side of ***Zeta*** by one turntable bearing kit, and is readily detachable to aid transport, storage, and customization. When in use, the ROV is positioned near the valve, wedging the valve turner into the valve, where the valve is turned by electrically activating the turntable bearing kit.

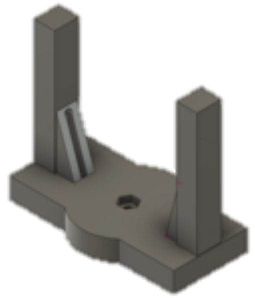


Figure 23:Overview of valve turner

Agar collector

The agar collector is constructed of a PVC tube and is made to draw agar samples in Task 3. The edge of the PVC tube has been filed down to sharpen the edge to make it more convenient for cutting agar. The walls of the PVC are made as thin as possible to reduce the obstruction from water pressure when cutting.

When in use, the ROV is positioned directly above the specimen, hovering perpendicularly to the seabed. The agar collector is positioned near the base of the ROV, and when the ship lowers itself into the agar, the power of the thrusters are used to force the tube into the agar sample, cutting the sample clean from its specimen once the tube reaches the bottom. Water pressure ensures that the sample stays in the agar collector when transported to the surface of the water.

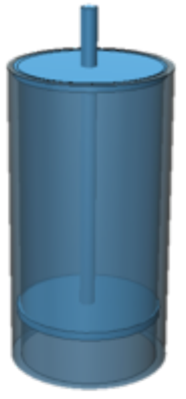


Figure 24: CAD diagram of Agar Collector

This method is simple and not costly. It works solely on kinetic movement - the fact that it does not depend on a motor reduces the need for wires or connections, reducing the possibility of tangles and the need for maintenance.

Spot light

Used for tackling Task 3, the spot light simulates the Raman spectrometer used for identifying polluted samples. It is positioned at the side of ***Zeta***, near one of the cameras, so that the pilot can accurately determine the spot light's position. The light is positioned downwards so that the ROV need only hover above the specimen during sample identification, cutting down on time.

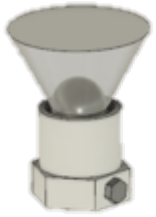


Figure 25: Overview of Spot Light

ScreenRuler

ScreenRuler is an application used for calculating the distance between the containers in Task 4. It is a programme and requires a computer to put it in use. It calculates distance by comparing the proportions of the same object in two different images.

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. A three-point tracing technique is used to frame the object in the captured image, which automatically calculates the dimensions of the object, tracking one specific side. Once its dimensions have been confirmed, no matter where the object is repositioned, the app will track the same specific side of the object, this time using two-point tracing only, and calculate the distance based on the proportions of the long shot compared to the close shot as displayed in fig 26.

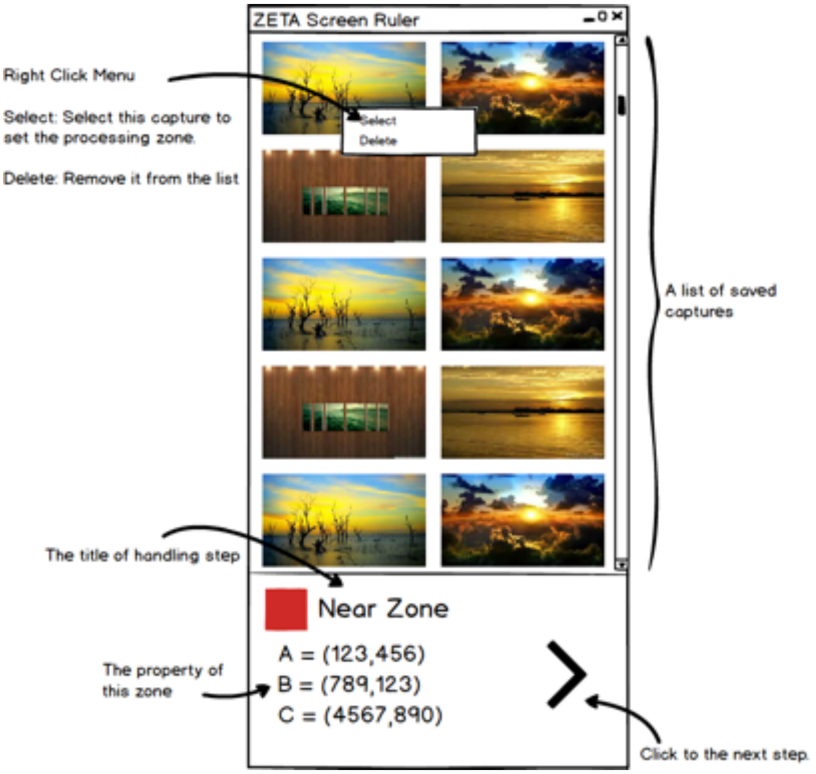


Figure 26: Screen capture of ScreenRuler

Safety Measures

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.

B. Safety Checklist

To ensure proper operation of our vehicles and the safety of our crew, a rigorous checklist is designed to 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, deployment, and teardown phase) procedures. The presence of at least two operators and the authorization of a senior engineer are needed every time for approval of the list and handling the ROV.

Safety Checklist

Staff names (in full): ______________________ and _______________________

Date and time: ____

Purpose of handling: ____

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 16A)

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 27: Safety checklist

C. Safety Features of *Zeta*

Mechanical Safety

Thrusters on ***Zeta*** come with their own safety covers to prevent the blades from contacting other materials, especially protecting human hands. 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 during operation. ***Zeta***'s frame was designed to ensure that there are no sharp edges. All corners of ***Zeta*** are rounded and streamlined.

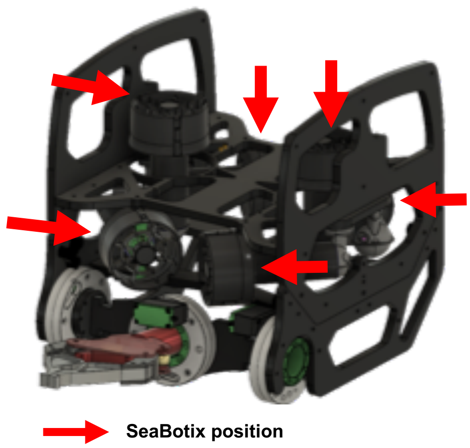


Figure 28: All propellers are shrouded

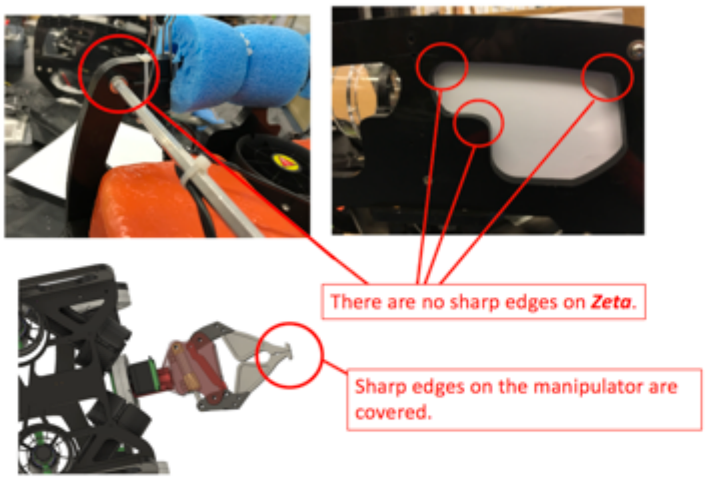


*Figure 29: No sharp edges on **Zeta***

Electrical Safety

A large red emergency stop button is located on our EDCP to cut the power source from the tether to ***Zeta*** in case of an emergency situation in our electrical system. We installed 2 circuit breakers - A 25A circuit breaker is placed at the beginning part of the circuit to prevent the overpowering of the electrical system; where another 25A circuit breaker, is the main switch of ***Zeta***. 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 ***Zeta*** is in stable operation. In addition, the emergency switch button can switch off all communications and power lines shared with ***Zeta***.

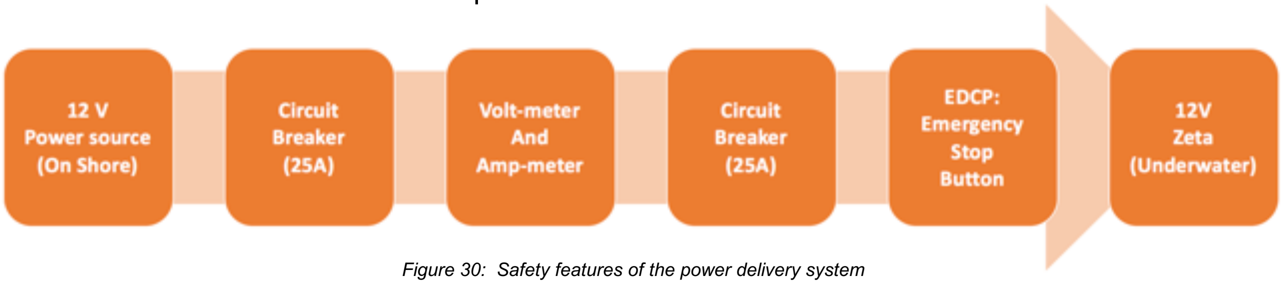


Figure 30: Safety features of the power delivery system

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

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 an 8-shape rather than in circles, to reduce inductance and further pressurization to the cable. This extends tether life, at the same time minimizing the possibility of power leakage on and off shore.

Figure 31:
Jayden coiling the tether into an 8-shape

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 lasts for 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. With proper training and standard tests, we can guarantee our ROVs are controlled and operated by qualified members.

Figure 32:
Newcomers and returning members having safety training section

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.

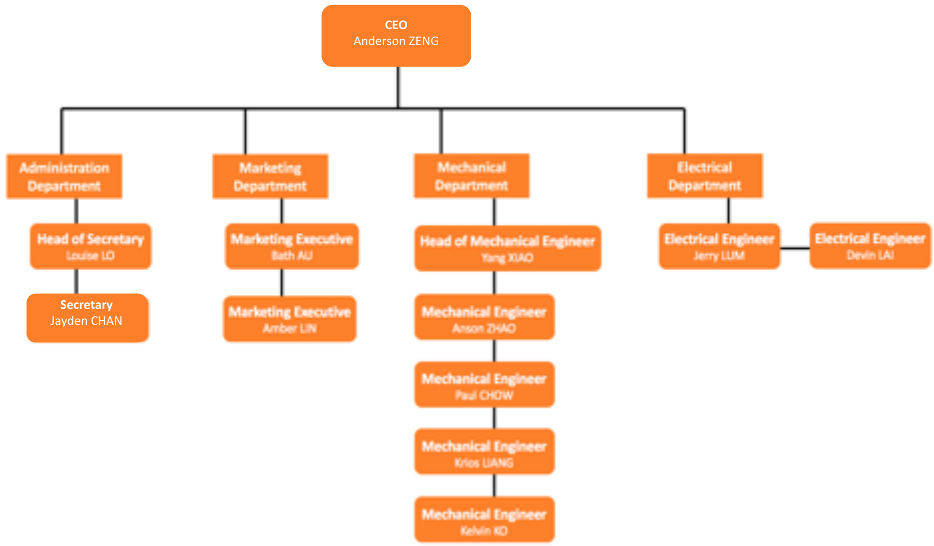


Figure 33: Hierarchy chart of CMA Underwater Expert Ltd.

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 morning meetings and daily debriefing sessions, so as to ensure that ***Zeta*** will be ready for the MATE ROV competition.

Schedule

	2016		2017					
Name	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUNE**
Louise LO *Head of Secretary*	Calculate the budget of Zeta	Research about how to make the Port of Long Beach healthier and safer for its citizens and waters Prepare the financial report	Job Site Safety Analysis Safety Checklist	Write the technical documentation Company Safety Review		ROV testing Practice sale Presentation	Receive the comment from regional contest and improve the technical document and marketing display	
Jayden CHAN *Secretary*								
Anderson ZENG *CEO*			Prepare the financial report Write the technical documentation			Practice Presentation	Plan the trip for International ROV Competition Los Angeles (Air ticket and accommodation)	
Beth AU *Marketing Executive*	Get to know ROV design Design the safety checklist	Take and edit photo of ROV, mission tool, group				Taking record for ROV testing		Practice the product presentation and product demonstration Prepare the document for transportation Packing all the competition equipment and shipping to competition venue
Amber LIN *Marketing Executive*		Design Logo	Design and edit marketing display				After the regional contest, improve the performance of all mission tools	
Paul CHOW, Anson ZHAO *Mechanical Engineer*		Build and test camera Test EDCP	Build tether Design and build manipulator Design and build the mission tool: Raman Spectrometer, Cigar Collection, Clamp Hand, Buoy Marker Build and attach the Styrofoam Attached thrusters on the ROV Make prop Waterproof test			Modify the function of components and ROV ROV testing		
Krios LIANG, Kelvin KO *Mechanical Engineer*		Design ROV structure Use Sketchup to create initial design of ROV and manipulator						
Yang Xiao *Head of Mechanical Engineer*								
Jerry LUM, Devin LAI *Electrical Engineer*		Design and develop the program of control system and electrical system Write GUI				Practice sale presentation	After the regional contest, improve the performance of control system, electrical system and tether	

Figure 34: 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 principal and fellow teachers in the fundraising activities, this year a budget of USD 31993.3 was obtained to support the MATE ROV competition.

To make ***Zeta*** more affordable and hit target costs, certain components from our previous ROVs were reused. This year, we spent USD 21191.22 for purchasing new parts with a surplus of USD 7065.49. The CMA Underwater Expert team, together with its supervisors and mentors, had altogether contributed an approximate 3,500 hours for planning, designing, building and testing in this project since September 2016. The financial report is shown on the right side.

Financial Report for Zeta (September 2016 - May 2017)					
Income					
Income	Description	Type	Qty	Cost Per Item(USD)	Total Cost (USD)
Prize Money	IET/MATE Hong Kong Underwater Robot Challenge 2017	Sponsored	N/A	N/A	1283
School Fundraising	For International Competition from School Bazaar and other Fundraising Activities	Donated	N/A	N/A	24,200
School Funding	For Regional Competition from CMA Secondary School	Donated	N/A	N/A	6510.3
				Total of Income	31993.3
Expenditure					
Expenditure	Desription	Type	Qty	Cost Per Item (USD)	Total Cost (USD)
ROV Parts					
High-density polyethylene (HDPE) Frame		Purchased	N/A	N/A	385
SeaBotix BTD 150 Thruster	Re-used from 2013 ROV (Gamma)	Re-used	4	769.23	3,076.92
Dome	/	Purchased	1	240	240
Tether Cabling	15m (1 for 12V Power Chord, 1 for 8 Control Signal Cores, 2 for Optical Fiber)	Purchased	1	N/A	390
Sealed Connector	Used in Motors, Electronic Speed Contollers	Purchased	32	2.56	82.05
170-degree Wide Angles Camera	Dome Camera and Front and Back ROV camera	Purchased	8	5.77	46.15
LED Light	Re-used from 2015 ROV (Delta)	Re-used	1m	6.41	6.41
Styrofoam	/	Purchased	1	3	3
Manipulator Components	PLA, Turntable Bearing Kit, Actuator	Purchased	N/A	N/A	360
Optical Video Transmitter	Video Signal to Media Convert	Purchased	2	16.03	32.62
Electronic Speed Controller	/	Purchased	7	19.23	132.62
				Sub-total of ROV Parts	4,754.77
Mission Tools					
Clamp Hand	Materials: PVC, Task 1	Self-made	2	4	8
Elastic Clamp	Materials: TPE, Task 1	Self-made	1	5	15
Valve Turner	Materials: PLA, Task 2	Self-made	1	5	15
Agar Collector	Materials: PVC, Task 3	Self-made	3	5	15
Spotlight	Task 3	Purchased	1	13	13
Buoy	Materials: PVC, Task 4	Self-made	1	10	10
				Sub-total of ROV Parts	76.00
Electrical Distribution Control Panel (EDCP)					
VEX Contoroller Kit	Re-used from 2012 ROV (Alpha)	Re-used	2	205.13	410.26
Optical Video Receiver	Video Signal to Media Convert	Purchased	2	16.03	32.05
24-inch Monitor		Purchased	1	312.5	312.5
8-channel DVR		Purchased	1	250	250
Optical Video Transceiver		Purchased	1	25	25
Water Proof Case		Purchased	1	286	286
220V AC to 12V DC Converter	/	Purchased	1	12.82	12.82
4Channel Network Video Recorder	/	Purchased	2	32.05	64.1
Minerature Circuit Breaker	25A DC Type	Purchased	1	1.28	1.28
Amp Meter		Re-used	1	2.56	2.56
Volt Meter		Re-used	1	2.56	2.56
Miscellancous Components	LED Signal Lights,Switches,Wires,Connentors	Purchased	1	12.82	12.82
				Sub-total of EDCP	1411.95
Others					
Comsumables	Sand Paper, Glue, Drill Bits, Epoxy, Solder, Saw Blades, Zip Ties	Purchased	N/A	N/A	128.21
Hire Life Guard	ROV Water Testing	Purchased	N/A	N/A	420
Printing	Marketing Display	Purchased	N/A	N/A	70
Logistics Expenses of ROV	Courier and other Delivery Cost	Purchased	N/A	4800	4800
Team Gear	T-shirt Printing	Purchased	18	12.5	225
Transporation	AirFare and Local traffic	Purchased	18	489	8802
Accomodation	Hotel Booking (8 nights)	Purchased	5 Rooms	98	3920
Souvenirs	Self-designed Stationary	Self-made	40	1.5	60
MATE Fees	MATE Competition	Purchased	N/A	N/A	145
				Sub-total of Others	18,570.21
				Total Expense of Re-used(ROV) in USD	3,643.59
				Total Expense of Purchased(ROV) in USD	21191.22
				Total Expense of Self-made(ROV) in USD	93.00
				Total Expenses of Zeta in USD	**24,927.81**

*Figure 35: Table of financial report of **Zeta***

A. Challenges

Technical

The electricity supply restriction is one of the toughest obstacle when designing ***Zeta***. Since we had been competing in Explorer Class for the past two years, our engineer needed to be readopted to the Ranger Class voltage restriction of 12V rather than 48V of Explorer's. With that much of a power downgrade we needed to make sure that our calculations and executions were precise to ensure most efficient power utilization.

Figure 36: Using 8 AWG power cable for power transmission

The frame of the ROV must also remain as compact as possible to minimize water resistance, which further makes the use of power more efficient. While test driving, ***Zeta*** experienced a power overload, which we later found out was because all 6 thrusters had been operating in full power. After calculation, the maximum ***Zeta*** can afford is operating 4 thrusters at the same time. A Pulse-width modulation (PWM) is programed to overcome the problem- when ***Zeta*** ascends, both vertical thrusters will operate in full power; when Zeta is rotating, or moving sideways, all other 4 thrusters will operate only in 50% power.

After the local MATE ROV Underwater Challenge, we re-examined ***Zeta*** and we discovered that with its current weight it is impossible for us to further improve its efficiency and its functions while keeping its weight within the limit. Therefore we have decided to opt for smaller and lighter thrusters from SeaBotix instead of the original SeaBotix thrusters, to free up weight capacity for us to work with. We also found our old control panel extremely burdensome to carry, thus we built a completely new panel which significantly enhanced its mobility.

Furthermore, we overcame some severe accidents. The redesigned hydraulic manipulators leaked oil and had to be re-sealed to ensure proper functioning. The manipulator suffered serious damage during shipping and storage, thus extra time and efforts were spent on making a replacement.

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.

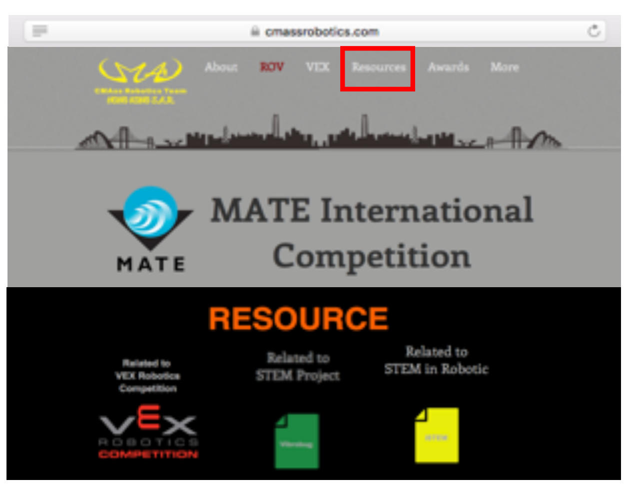


Figure 37: Open-source learning platform at www.cmassrobotics.com → Resources

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 basketball matches, 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: Our supervisor - Mr. CHEUNG team building with newcomers

B. Troubleshooting

Troubleshooting is essential to the success of ***Zeta***. 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 the Troubleshooting Approach of our company; 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.

One of our contingency designs customized to aid troubleshooting is applied to the manipulator's Design. It is observed that the manipulator has a high possibility of overloading, and breaks down when it bears too much tension in operation. To maintain the stability of the manipulator , a colour stripe is marked on each of its arms to indicate how close it is to its maximum opening width. Going back to basics, when the clip opens up to its benchmark, the pilot should be alerted and be mindful when controlling the manipulator, to avoid overloading.

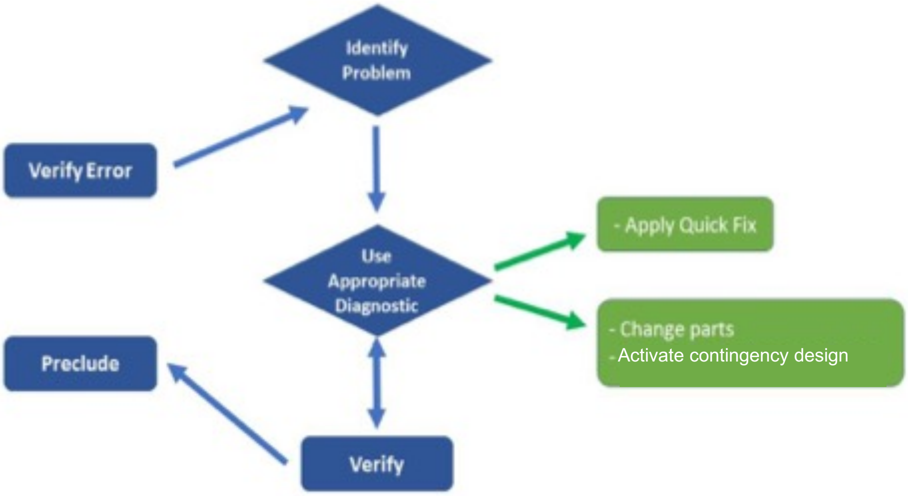


Figure 39: The Troubleshooting Approach of CMA Underwater Expert Ltd.

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 could not be taught in class.

Technical

The manipulator is an indispensable tool, which is required in nearly all the tasks. To customize the manipulator into an omni-functional tool suited for various tasks, 3D printing was adopted to create a unique set of claws and parts. The manipulator was originally inspired by a patented design, where it was re-innovated and modified, especially the tip of its claws, to fit ***Zeta***'s needs. The design was redrawn into a computer-aided design (CAD) drawing with Autodesk Fusion 360, a CAD drawing programme, and converted into STereoLithography (STL) format for outputting to a 3D printer. Members learnt how to draw CAD drafts with 3D modelling software, execute a design, and realize it into a virtual design, and even engineer their own designs.

Figure 40: 3D printing used for making manipulator

Interpersonal

We have further reinforced our strong team spirit and interpersonal skills in this journey. The creation of the sophisticated ***Zeta*** requires countless time and efforts. As a result, 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 was working on the design of ***Zeta***, 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 work with and respect each other.

Figure 41: Members discussing important decisions

D. Future Improvement

Figure 42: Mentoring scheme for learning setting up

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

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

Anderson ZENG CEO (Grade 11)

I would like to thank MATE and my team for providing me with opportunities to utilize my skills and further explore my potential. Since this is my first year participating in the MATE ROV competition, I once feared that my inexperience would hinder our progress, but because our team has had 10 years of experience, there's no shortage of experienced mentors that I can learn from.

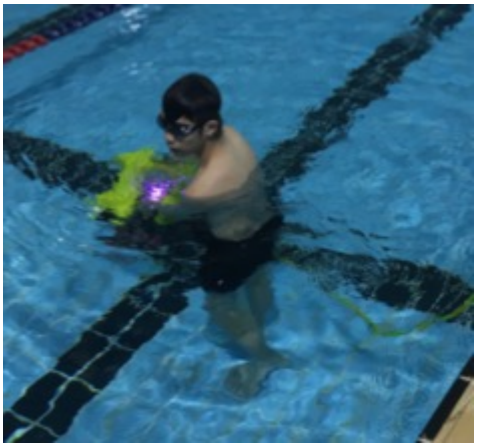


Figure 43:
CEO Anderson repositioning ***Zeta*** *during water test*

Participating in the ROV competition has put my abilities in dealing with various situations to the test. From my days with ***Zeta***, I have gained a lot of mechanical knowledge and polished my social skills. Taking up the role of CEO as a rookie of the competition was quite overwhelming at first, from arranging plans to implementing and integrating the strategic direction of our team - everything was brand new to me. However, being unexperienced has its perks as I am more motivated to explore new methodologies while handling handling different situations. In addition, I have learnt to expand my vision to see steps further to provide my team with valuable and insightful recommendations.

Although most of the members are new to the team, all of them are highly motivated to build an efficient and highly qualified ROV. It has been an honor working with this passionate group of people. Of course, we have had our ups and downs, our fair share of bumpy roads, and heavy winds - but in the end, we always overcome them as a team, stronger than before. I believe that everyone in the team has greatly benefited by participating in this year's MATE ROV competition.

Louise Lo , Head Secretary (Grade 10)

This is my very first time being the coordinator of the team. Thinking that it was an easy job, it turned out to be way more complicated than I thought. My photo taking skills had really been put to the test since I had to document each step and moment of the team, including the condition of the ROV. I had to ready myself for any accidents and be extremely careful not to miss out on any details. Communicating with my team members was also very important since upholding the spirit of a team is the key to success. In addition, I had to deal with both technical issues and paper work. Furthermore, I had to oversee different processes and make sure that things ran smoothly. Time and manpower management was critical to our project. It was very important to make sure that everyone was delegated tasks that corresponded to their abilities. Keeping the working environment clean and safe was also essential. This experience benefits me in many ways, including helping me develop into a more responsible, considerate and organized person.

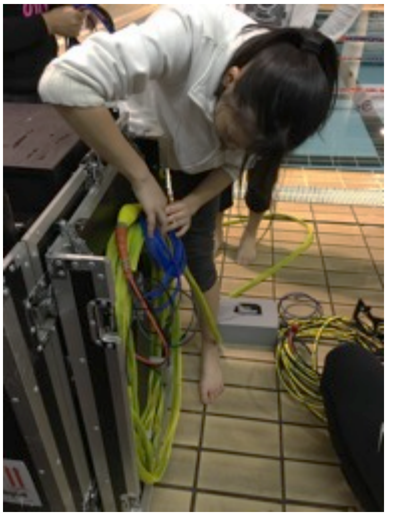


Figure 44:
Head Secretary Louise helping for clear up after water test

F. Reference

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Figure 45: Logos of the acknowledged parties