HONG KONG

THETA

TECHNICAL DOCUMENTATION

2019 MATE INTERNATIONAL ROV COMPETITION

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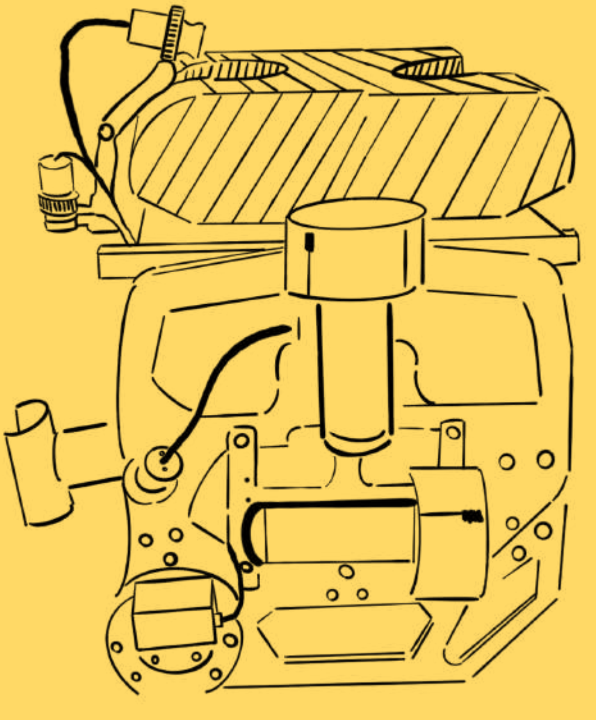

CMA UNDERWATER EXPERT LTD.

CMA SECONDARY SCHOOL, CMASS ROBOTICS TEAM

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Abstract

This year we celebrate our 12th year involving in Remotely Operated Vehicle (ROV) development and research. ***Theta*** marks this incredible date and shows the techniques and experience we acquired throughout the years. We, CMA Underwater Expert Limited, is confident that ***Theta*** is capable of satisfying Eastman's proposal for and ROV suitable for operating in the freshwater environments of Boone Lake, Boone Dam, and the South Fork of the Holston River.

Custom-made for this year's tasks, ***Theta*** is capable of inspecting and making repairs to a hydroelectric dam, monitoring water quality, determining habitat diversity, and recovering a Civil War era cannon, and marking the location of unexploded cannon shells.

Standing at 42cm (L) x 52cm (W) x 43cm (H), ***Theta*** is small for its class but has formidable functionalities. ***Theta*** is equipped with 4 Seabotix thrusters and has a frame made of High-Density Polyethylene (HDPE), and only requires a small buoyancy device, making the ROV much more agile yet enabling multi-directional movement.

Specially designed mission tools, such a Micro-ROV, an image recognition software, an inflatable air bag, and heavy-duty lift tools, were tailor-made for this year's missions, which require the ROV to do measurements, recognize shapes, transport weights, and detect metal.

With the combined efforts of our company members, our great passion, and our technical skills, CMA Underwater Expert Limited designs adequately fulfill and adjust to varying specifications. This document details the technical aspects of ***Theta***, CMA Underwater Expert's origination of 2019.

Figure 1: Team photo *(Listed from left to right)*
(Top left) Tommy YEUNG, Anderson TSANG, Jacky MA
(Bottom left) Samuel HUI, Gordon LO, Terry AU, Beth AU

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. Compared to our last ROV, we have further reduced its weight to 11.4kg. ***Theta*** targets at maximizing its maneuverability by limiting the diameter to no greater than 60cm.

The second objective is to improve our ROV's usability by fitting a voltage regulator on the Electrical Distribution Control Panel (EDCP). By widening the voltage adaptability, ***Theta*** is more tolerant to relatively unstable power supply. Many aspects of the ROV have also been recalculated to allow the ROV to be more adaptive and practical for all situations.

For our third objective, we aim to cultivate our younger team members to be the future backbone of the company. In previous years, cultivating younger members was important, but never our top priority and the team was mainly dominated by senior members. Our talent loss rate became dangerously high due to graduation of senior members, which created handover issues. By preparing our younger members sooner, said problems can be eliminated, and we can pave the way for a better future for our team.

B. Design Process

In pursuit of an ROV which is compatible with our company's standard and the requirements of MATE 2019, we started evaluating our setbacks soon after the local competition, listing out the deficiencies and potential problems that we would likely encounter with 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.

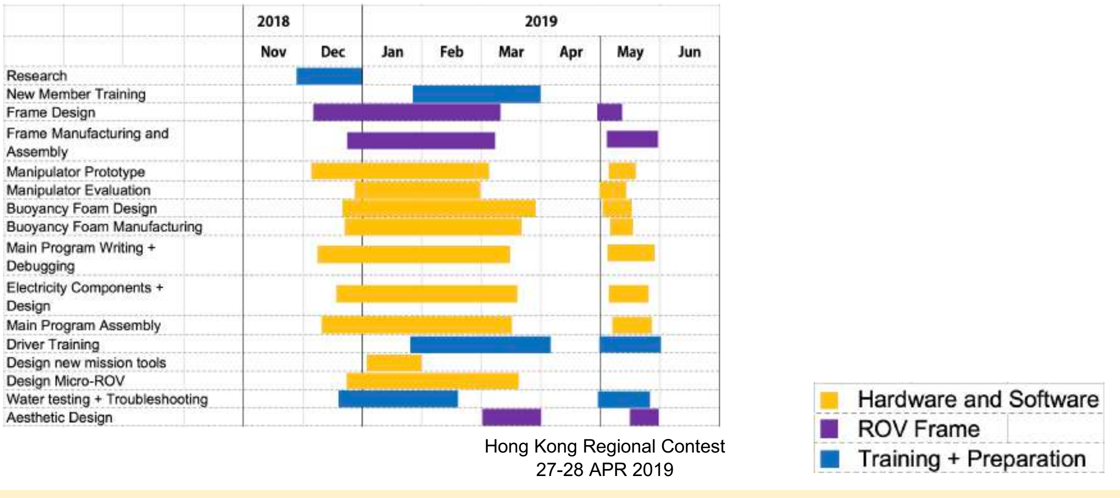


Figure 2: The development timeline
(Diagram by Terry AU)

C. Design Philosophy

To provide the most efficient ROV for customers to satisfy various tasks in diverse circumstances, ***Theta***'s design philosophy focuses on reliability and accessibility. Owing to its robust HDPE chassis, ***Theta*** is a sophisticated machine in a sturdy package. Most components are made in-house, aiding quality control. Furthermore, we only choose quality products for the components we purchased. The all-in-one control panel of ***Theta*** is specially designed for quick and convenient set up for maximum accessibility. All controls are fine-tuned.

D. Overview (Sketches and Drafts of *Theta*)

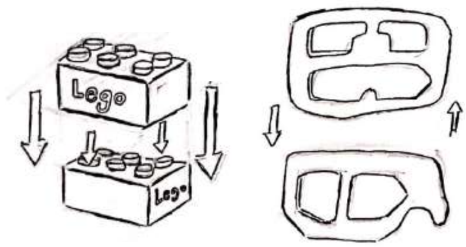


*Figure 3: Concept drawing of **Theta**'s frame (Drawing by Beth AU)*

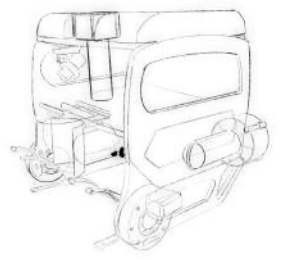


*Figure 4: Concept drawing of **Theta** (Drawing by Beth AU)*

Once we validated the concepts through sketches (as shown in Figures 3 & 4), a detailed 3D Computer-Aided Design and Drafting (CAD) model was used to simulate our initial design, especially to help us visualize and estimate our frame size, core component placement, and weight balance. Autodesk Fusion 360 was then used to connect the entire product design.

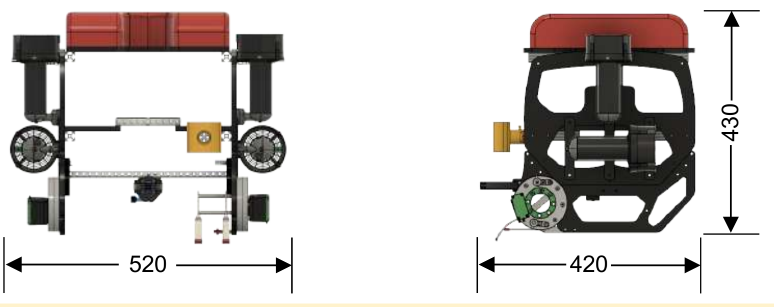
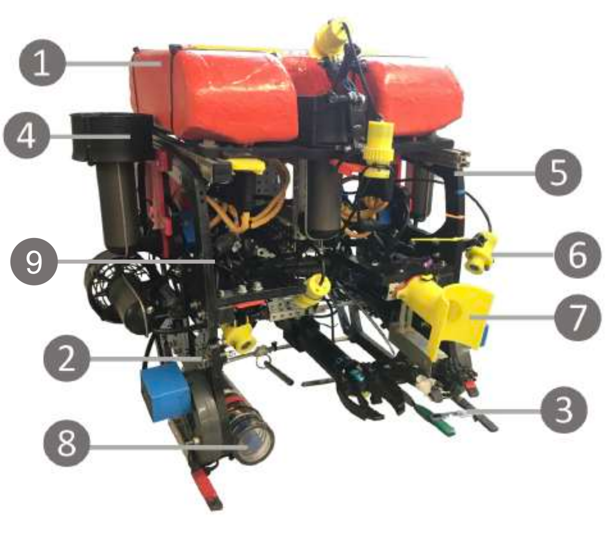


*Figure 5: CAD model of **Theta** with Autodesk Fusion 360 (CAD Drawing by Beth AU)*

Through using a CAD model (Figure 5) to visualize the design of the ROV, company members involved more in the design process by sharing ideas and discussing freely without the hassle of taking the time to rebuild the ROV. Tool placement and can also be simulated in the CAD design, helping builders anticipate bugs and improvements that can be made. Necessary changes were incorporated until the ideal design was achieved.



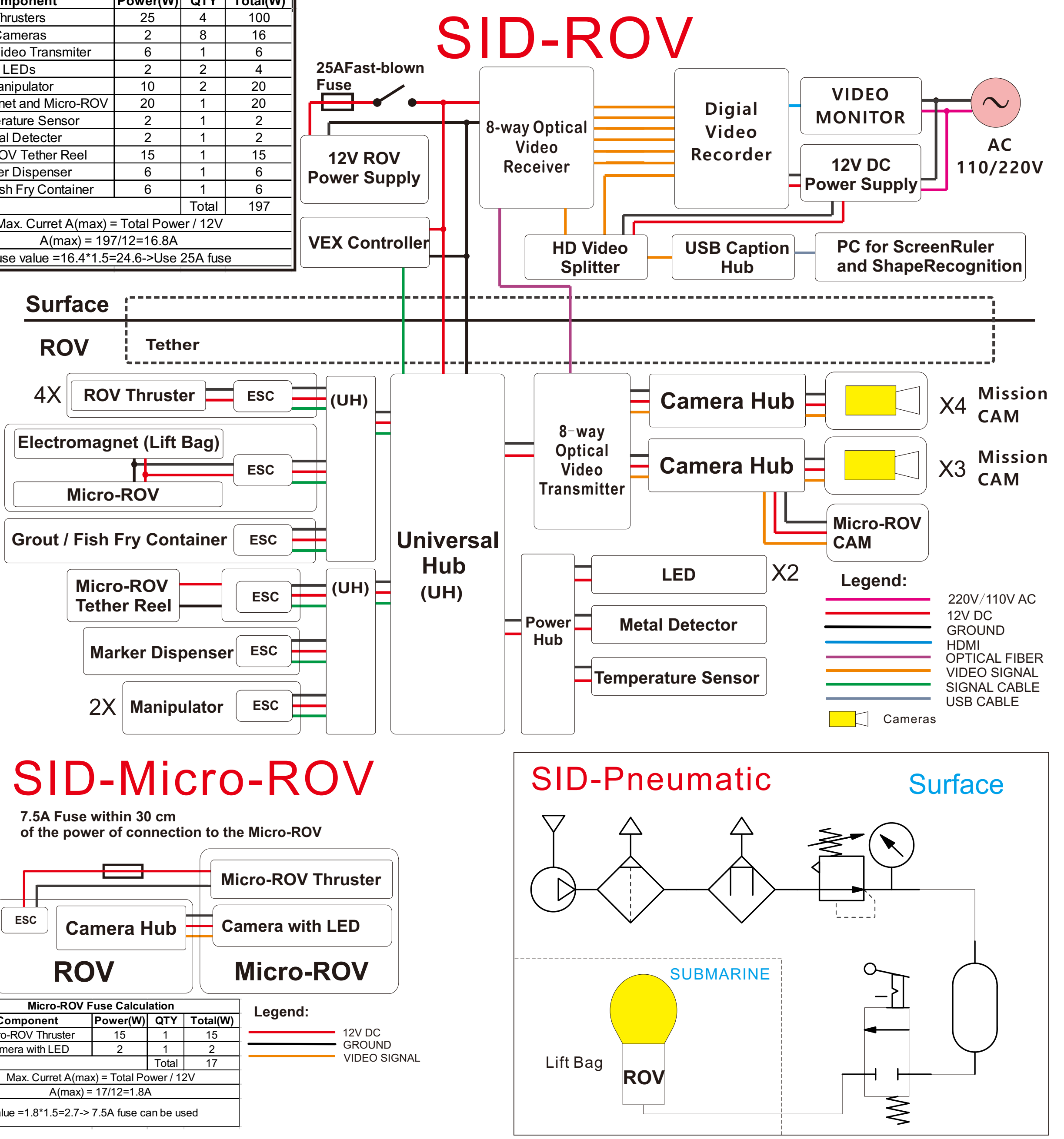
	Components
1	Buoyancy made from polystyrene fiberglassed with epoxy
2	Micro-ROV Dock and tether reel
3	Manipulator with parallel closing arms
4	Thrusters for upward and downward movement
5	Frame made from High-Density Polyethylene (HDPE)
6	HD Cameras with 120º view angle
7	3D-printed lift bag holder (electromagnet attachment)
8	Metal Detector
9	LED Light for supplying powerful light source in dark environment

*Figure 6: Final design of **Theta** (Image by Terry AU)*

THETA

E. System Interconnection Diagram (SID)

Fuse Calculation			
Component	**Power(W)**	**QTY**	**Total(W)**
Thrusters	25	4	100
Cameras	2	8	16
Optical Video Transmiter	6	1	6
LEDs	2	2	4
Manipulator	10	2	20
Electromagnet and Micro-ROV	20	1	20
Temperature Sensor	2	1	2
Metal Detecter	2	1	2
Micro-ROV Tether Reel	15	1	15
Marker Dispenser	6	1	6
Grout / Fish Fry Container	6	1	6
		Total	197
Max. Curret A(max) = Total Power / 12V			
A(max) = 197/12=16.8A			
Fuse value =16.4*1.5=24.6->Use 25A fuse			



Micro-ROV Fuse Calculation			
Component	**Power(W)**	**QTY**	**Total(W)**
Micro-ROV Thruster	15	1	15
Camera with LED	2	1	2
		Total	17
Max. Curret A(max) = Total Power / 12V			
A(max) = 17/12=1.8A			
Fuse value =1.8*1.5=2.7-> 7.5A fuse can be used			

*Figure 7: SID of **Theta** with CorelDraw*
(Diagram by Tommy YEUNG)

Using optical fibers to transmit camera signals conductively reduces interference. They also keep ***Theta*** light and ensures its tether stays thin. The control signal from the 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

Theta is connected to a 15-meter long tether, consisting of one 8 AWG power cable, four optical fiber cables, one 8 core-signal cable, two airline tubings, and one wire. The power cable is used to provide power to ***Theta***, while the 4 core-signal cable is used for communication. 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 use eight digital cameras, an optical fiber is used to transmit camera signals to our monitor display. A flexible wire prevents the tether from cracking. An airline tubing supplies air used to inflate our lift bags used in Task Three, while the other acts as a spare.

(Please see p.17 for details on tether safety)

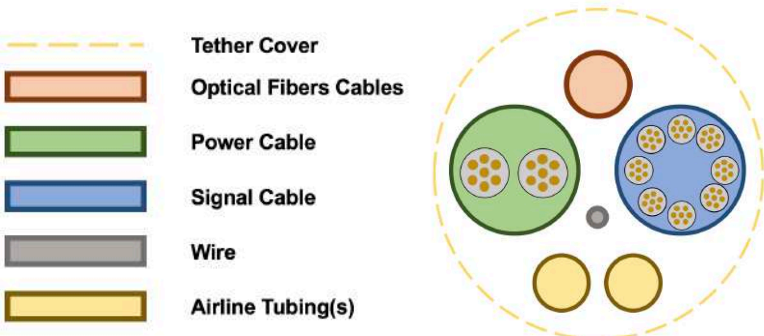


*Figure 8: Cross section of **Theta**'s tether*
(Image by Beth AU)

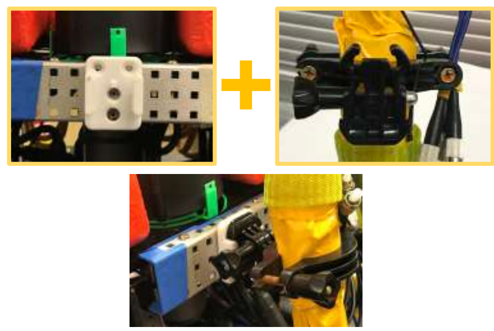


Figure 9: Photo of tether locker
(Image by Beth AU)

G. Frame

To reduce the weight and size of the ROV without sacrificing strength and durability, ***Theta***'s frame is built from High-Density Polyethylene (HDPE), a medium 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). This aids the buoyancy system of ***Theta***, reducing its dependence on a large float or ballast. HDPE can be easily manufactured by using a Computer Numerical Control Cutter (CNC Cutter), and the rigidness of HDPE protects the ROV's core while keeping interior structures intact. HDPE is also cheaper than most other materials.

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

The open frame of ***Theta*** provides minimal obstruction and houses the electronic speed controllers, optical fiber receivers, and its 6 thrusters. All fixed electrical components are placed in the main frame to condense critical parts.

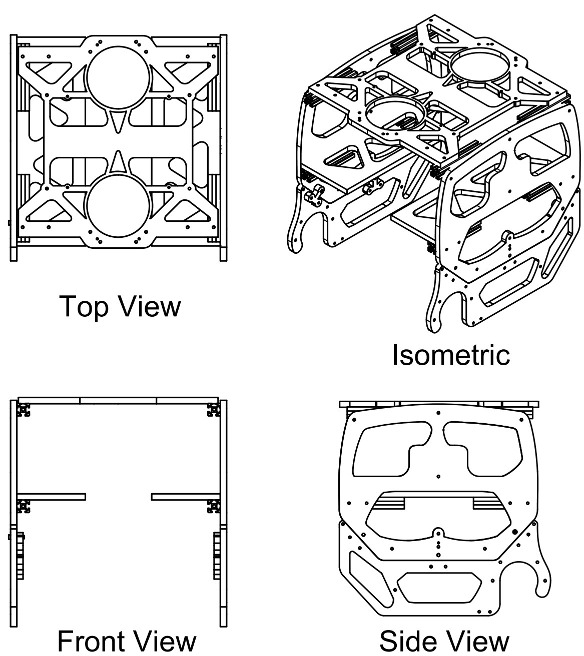


*Figure 10: Overview of **Theta**'s frame with Autodesk Fusion 360*
(CAD Drawing by Beth AU)

The bottom part of the frame allows room for the installation of an interchangeable subframe. This year's subframe houses the two manipulators the Metal Detector, the Clamp, and the Grout Filler. In cases where maximum agility is required, the subframe can be completely removed, allowing water convection to occur, further minimizing water resistance.

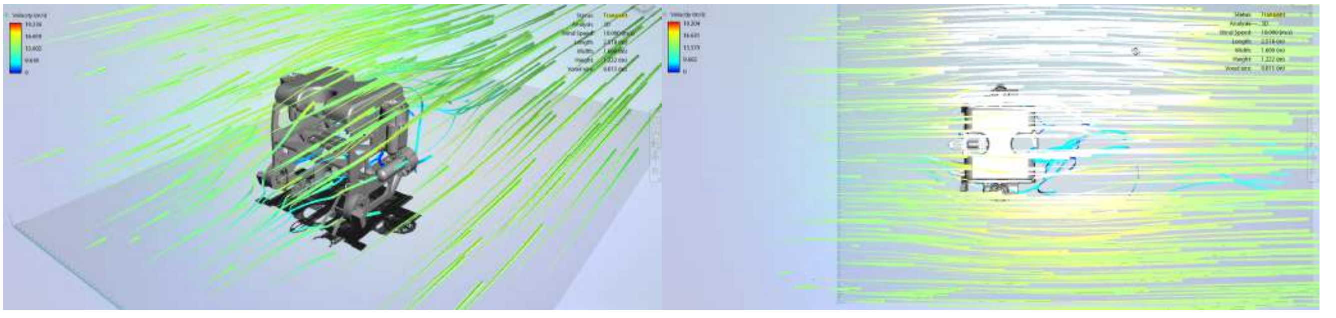


*Figure 11: Flow test simulation of **Theta** with Autodesk Flow Design (CAD Drawing by Beth AU)*

Autodesk Flow Design (Autodesk) is used to help simulate the performance of the ROV underwater. Using the data analysis provided by Autodesk, we have been able to conduct numerous tests to refine ***Theta***'s design and performance by reducing water resistance.

The most efficient feature of ***Theta***'s frame is its easily detachable compartment, which can be separated into two sections swiftly by by removing six screws. It This feature enables the clear monitoring of all components during mission and makes maintenance convenient. Its easy installation also prevents damage while shipping.

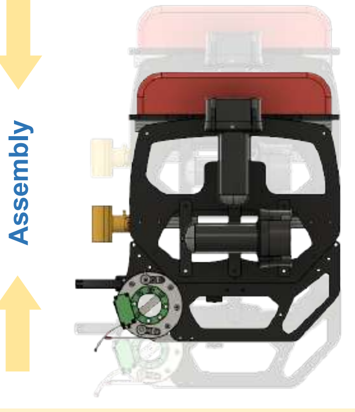


*Figure 12: **Theta**'s quickly detachable subframe with Autodesk Fusion 360 (CAD Drawing by Beth AU)*

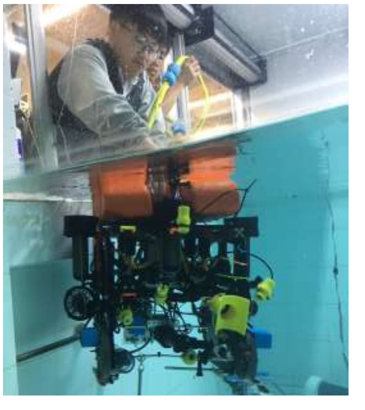


*Figure 13: Front shot of **Theta** in water (Image by Beth AU)*

H. Electrical Distribution Control Panel (EDCP)

The Control Panel is the main control system for ***Theta*** that holds the on-shore Tether Control System (TCS), communications, tether connecting to the ROV, and onboard electronics altogether. All onshore electronics are gathered in one flight case for better integration, safety, and convenient troubleshooting.

A 25A fuse is included at the side of the power input as a safety feature to minimize the accidents under operation. In addition to the 25A fuse, there is a power toggle button controlling the power supply to all major networking components inside the TCS. Voltage and current meters are installed to allow pilots to monitor power issues, such as discharged batteries and short circuiting.

Camera signals are transmitted through an optical fiber transmitter installed on ***Theta***. The optical fiber transmitter transmits camera signals, and optical fiber receivers on the EDCP convert the cameras' signals into video images. The video images are sent to the Digital Video Recorder for regrouping, centralizing the 8 camera images on the same monitor. This provides pilots with a full and clear picture during operation.

One VEX Controller Kit is connected to the Control Panel to send signals to the Electronic Speed

Controllers, which then control the thrusters. The 24-inch monitor is mounted for better scanning during operation. All the electronic components in the Control Panel are newly bought to replace the old and faulty ones.

A separate Surface Pro notebook with Windows 10 installed is used for data analysis, software trouble shooting, and running image recognition application. The notebook is only 29.2cm x 20.4cm x 8.5cm in size, which makes it very convenient for carrying and usage.

A lighter and smaller table top version was developed during our 2017 run but was damaged in transit and malfunctioned during product demonstration. We realized that there are too many delicate electronic parts in our EDCP that require meticulous protection, hence we switched back to our original flight case and focused on improving its functionality and maintenance instead.

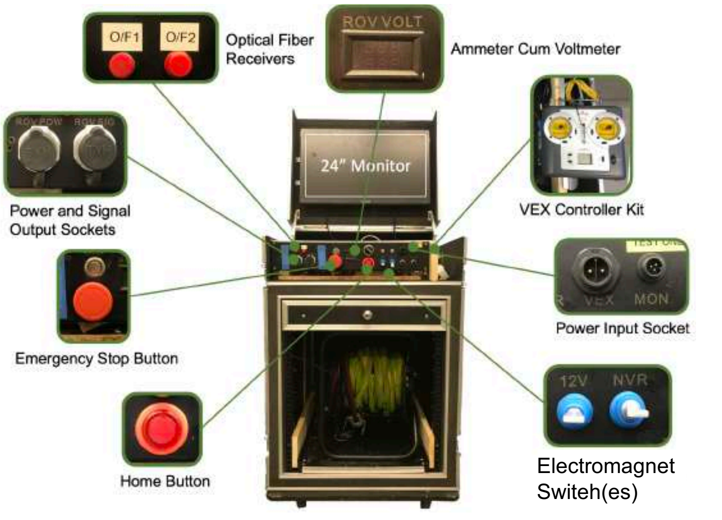


Figure 14: Features of the EDCP (Image by Terry AU)

I. VEX Controller Kit

The ROV is controlled by one VEX Controller Kit which controls the motion of ***Theta*** through its 6 thrusters, the swivelling door of the Grout/Fish Fry Container, the main BlueRobotics manipulator, a turntable bearing kit for the side manipulator, another turntable bearing kit for the Micro-ROV's tether retracting mechanism, and operating the Micro-ROV's thruster.

This control system consists of a 750MHz RF transmitter, a receiver remote control, a joystick, a radio transmitter unit, and a compatible receiver unit. The presence of such units allows easier accommodation for future expansions of the ROV subsystems.

VEX controllers are among the small number of reused commercially-made components. This is because constructing a controller from scrap is too advanced for our level, and also because our ROV drivers are highly experienced VEX drivers (averaging 600 practice hours per person annually) VEX controller is the tool they are most familiar with, compared to other branded joysticks or controllers. Their mature manoeuvring skills are a great asset to the smooth running of missions. VEX controllers can also be stably powered through a USB cable from our EDCP, where most other controllers rely on batteries, with the hazard of running out of power mid-mission.

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.

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 ***Theta***. This year we used the same principles, but further reduced their size, weight, and manufacturing time all by

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 is simple and fundamental, ESC making workshops are also used to train our younger members, where their finished products contribute to ***Theta***'s parts, hence they are able to participate in the process of ROV making, and thus granted a sense of accomplishment.

Figure 15: Overview comparison of old and new ESC Boxes (Image by Beth AU)

K. Thrusters

Theta 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 ***Theta*** 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 ***Theta*** maintain balance and equilibrium.

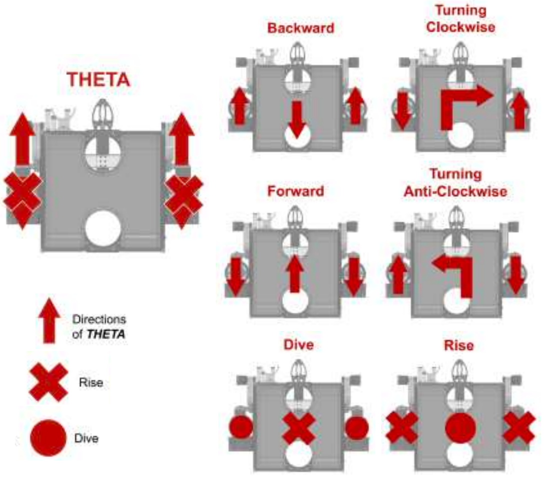


*Figure 16: Explanation of **Theta**'s propulsion system with Autodesk Fusion 360 (CAD Drawing by Beth AU)*

Each thruster provides a maximum of 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 ***Theta***'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 the 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

Theta is fitted with a floatation system designed to neutralize the ROV's water weight. The floatation system is comprised mainly of (i)its top floater and (ii)the main material of the ROV – HDPE.

Our company tests the buoyancy float by installing it on ***Theta***, 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 ***Theta***, before the addition of the float, was 10kg. ***Theta*** 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.

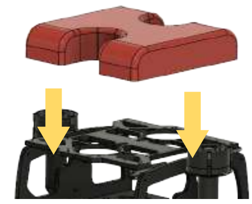


*Figure 17: The buoyancy board neutralizes the weight of **Theta** in with Autodesk Fusion 360 (CAD Drawing by Beth AU)*

M. Software Flow

RobotC is a free coding software we use to control ***Theta***. Writing the RobotC code controls the sequence of how the thrusters of the ROV function, which in turn controls ***Theta***'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 Pulse Width, ensuring that thrusters are not overloaded. This helps mitigate the risk of having to repair our ROV's thrusters mid-mission.

*Figure 18: Program flow of **Theta**'s control with CorelDraw (Design and image by Jerry LUM)*

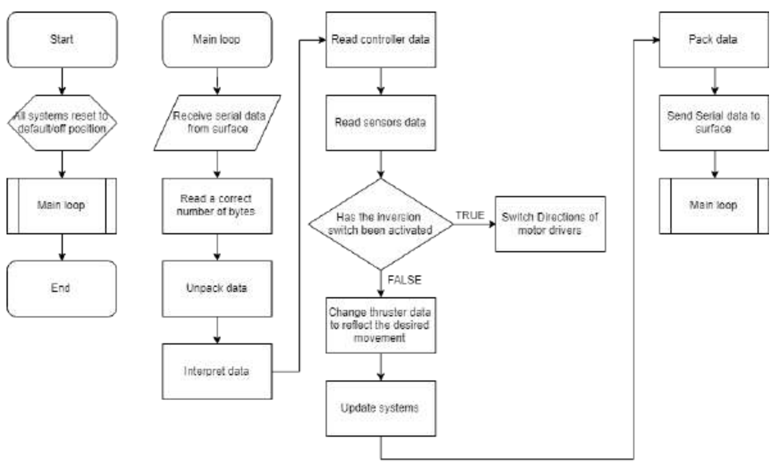


*Figure 19: Program flow of **Theta**'s control with CorelDraw (Diagram by Jerry LUM)*

N. Mission-Specific

Cameras ***(Post-production by Gordon LO)***

Glitch-free cameras are our keys to success. Through years of modification, we are now using a total of 8 camera images - one large image, and seven other smaller images, which are interchangeable and clearly labeled for the driver's convenience.

We are often questioned whether it is necessary to have this amount of images. Truth is, apart from having a great field of vision and almost no blind spots, a multi-angle view of our tools contributes to the accuracy of prop placement and observational tasks (e.g. recognising benthic species). Of our 8 cameras, 3 are used for general observation, 3 are close-ups of our manipulators and tools, and 2 are used for observational tasks (one pointing to the side, and one down from below the ROV).

Regarding tool accuracy, a few tasks require the accurate placement of props, like balancing the newtrash rack on a ledge (Task One), and placing reef balls and markers within small confined areas. Having two cameras (one top, one bottom) closing up on our manipulators gives the driver multi-angle vision, greatly increasing maneuvering precision. Regarding observational tasks, we have had problems observing the dam (Task One) with a front-facing camera, as our ROV does not move sideways efficiently. We repositioned our camera to the side, and traced the dam by moving the ROV forward and backward. A clear image is crucial for image recognition. A downward-facing camera (at the bottom of the ship) best captures an image of the benthic species at a perpendicular angle.

Regarding challenges, one of our cameras became mouldy, and had to be replaced. We made covers for our cameras, since cameras are scratch-prone and exposed to mechanical damage. We 3D-printed covers and filled them, cameras and all, in a 0.2-0.7mm layer of epoxy. Not only does this ensure that no air nor water penetrates through due to the PLA's (printing filament) water-absorbing qualities, but it also fixes their positions, so that bumping and other means of contact would not make the cameras lose their focus.

Figure 20: Placement of cameras (Image by Beth AU)

Clamp *(Designed and produced by Jacky MA)*

The clamp, inspired by the claw cranes in arcade claw machines, is used for lifting the tire and the canon in Tasks 2 and 3 respectively. Constructed with aluminium bars and joints, it has a auto-locking mechanism consisting of retracting arms assisted by elastic bands. When in use, the clamp is pressed downwards onto the target item, and its arms snap onto the item securely, and can only be detached manually on land.

Foam is added to help balance the ROV in water, as the clamp is considerably heavy. When in use, the clamp will be mounted on the left bottom rear end of ***Theta***, and loosened by a quick-release pin.

The clamp holds props firmly, and allows poolside members to haul thick and heavy props to shore. We opted for a self-made claw simply because there are very few clamps that are strong enough to handle extra-heavy props like the tire.

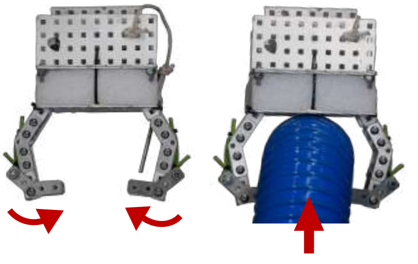


Figure 21: Demonstration of Clamp in use (Image by Beth AU)

Marker Dispenser *(Designed and produced by Samuel HUI)*

Theta is equipped with a Marker Dispenser stationed below the Grout/Fish Fry Container. It is used for placing the colored marker to indicate canon shells in Task Three.

The Marker Dispenser is based on the principle of a vending machine. Four cannon shell markers are hung separately on a coil, and as the coil rotates, the markers slide away from the coil, and are dispensed into the water to indicate debris composition.

The Marker Dispenser is connected to a motor and fitted with a transparent shield made of Polycarbonate (PC) to prevent the markers from floating away from the coil. During our pool trials, the colored markers (with floaters on them) always float away from the Marker Dispenser and fall down in inappropriate places.

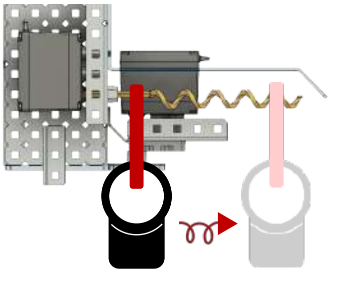


Figure 22: CAD model with Autodesk Fusion 360 for demonstration of the Marker Dispenser for placing the colored marker (CAD drawing by Beth AU)

Figure 23: A photo of Marker Dispenser (Image by Terry AU)

Grout / Fish Fry Container *(Designed and produced by Jacky MA)*

The Container is the vessel used to transport the grout filling in Task One and the fish fry in Task Two.

While designing the container, two concerns we had in mind were (i)how not to hurt the fish during transport (should this be used in a real-life scenario), (ii)ensure that the fish stayed in the container during transport, and (iii)whether the container was sturdy enough to hold the grout filling.

The current container we are using is composed of a aluminium rectangular prism with an acrylic door at the bottom that swivels open by a motor on the side. When ***Theta*** is in position, the door is opened and the grout or fish fry is released. Safety wise, the swivel mechanism is not located inside the prism, and hence will not pose any danger to the fish fry.

Another prototype was also developed which uses a PVC pipe as its body, with heavy-duty rubber bands serving as the releasing mechanism. 4 strands of rubber bands are stretched across the tube opening and act as a gate. Two other rubber bands pull the gates apart and allow the fish to escape.

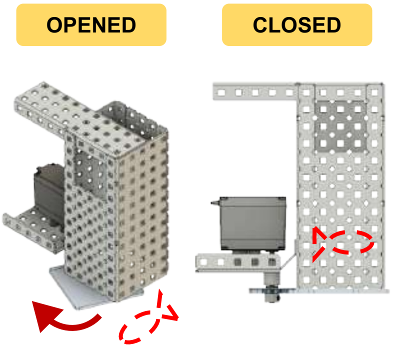


Figure 24: Demonstration of the Grout/Fish Fry Container for holding and placing fish (CAD Drawing by Beth AU)

The latter design a more ideal concept. The design is foolproof owing to its simple mechanism and design, which also takes into consideration the safety of the fish, as the materials used are all pliable, and there are no hinges involved that would trap and injure the fish. The problem is we are still experimenting with different materials and combinations, thus the presence of bugs. The currently more refined system, though electrically powered, will be in use until the new design is perfected.

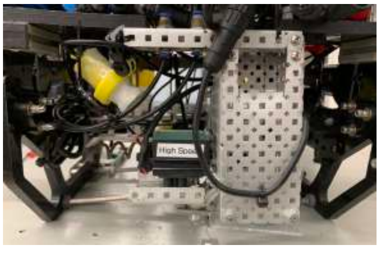


Figure 25: Photo of Grout/Fish Fry Container mounted on ***Theta***
(Image by Beth AU)

Manipulator *(Secondary Manipulator designed and produced by Gordon LO)*

Theta is equipped with 2 manipulators - one main manipulator in the middle from Blue Robotics that opens horizontally, and one secondary manipulator at the left foot of ***Theta*** that opens vertically. The secondary manipulator is reused from last year ROV. It is powered by a turntable bearing kit, with at least 2 cameras looking at them from different angles for maximum precision. We decided to reuse the manipulator to maximise ***Theta***' versatility, as we did not have a tool for gripping horizontal items.

The main manipulator is a short sturdy pincer with grooved arms, which us used for most tasks. It is capable of gripping thick and heavy items firmly, and its grooved arms work best at gripping vertical tubes, like the trash rack in Task One. The secondary manipulator consists of two upper arms and one lower arm (both made of bent aluminium bars), inspired by the talons of an owl. It is used for scooping items from the seabed. We decided to add an extra main manipulator, as the old one has difficulty aiming at props, and the gripping power of the main manipulator is far superior.

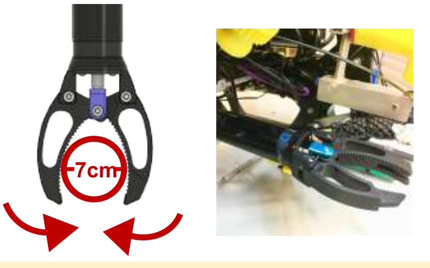


Figure 26: CAD model with Autodesk Fusion 360 and demonstration of the main manipulator (Image by Beth AU)

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

Figure 27: CAD model with Autodesk Fusion 360 and demonstration of ***Theta****'s secondary manipulators (Image by Beth AU)*

Micro-ROV *(Designed and produced by Samuel HUI)*

Designed specifically to inspect confined areas, our Micro-ROV is an excellent tool for examining underwater piping (Task One).

Standing at 5.5 cm x 8 cm x 9 cm, the Micro-ROV has a brushed thruster acting as the body with a Infrared Night Vision Camera mounted at the bottom, and three LEDs to further assist the driver's line of sight. The Micro-ROV draws its power from ***Theta***, with a 7.5 amp fuse at the point of connection. The brushed thruster comes with a shroud that meets the IP-20 safety regulation. Although the Micro-ROV is extremely light, two pieces of foam are still required to achieve neutral buoyancy. When in use, the driver points the Micro ROV at the entrance of the piping, release the tether of the Micro-ROV (managed by a turntable bearing kit), then activate the motors.

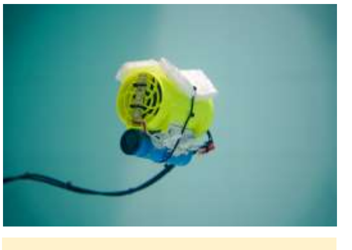


Figure 28: A photo of the Micro-ROV (Image by Beth AU)

When the inspection is done, the tether will retract, pulling the Micro-ROV out and docking it in the main ROV. The Micro-ROV is connected to ***Theta*** by copper wiring and a video signal cable. We focused on making it lightweight and cost-efficient as a prototype. All the materials used are inexpensive, widely available and light. The whole control system and design is simplistic, making it a very effective tool.

We originally planned on using a Seabotix thruster, since we changed the design of ***Theta*** from using six thrusters to four, leaving two available. However, its superior performance requires compromises. Its high power consumption, heavy weight, bulk, and the risk of burning an expensive component steers us towards opting for a much more light weight and expendable brushed thruster.

Lift Bag ***(Re-produced by Gordon LO)***

The Lift Bag is used for lifting the canon in Task Three.

Figure 29: Photos of lift bag, deflated vs. inflated
(Image by Beth AU)

Inspired by a similar lift bag we made for MATE ROV 2018, the Lift Bag consists of a water-proof bag zip-tied to one open end of a 10 inch x 2 ½ inch PVC tubing. The other end has a sturdy stainless steel hook for lifting, and the inlet situated above the hook receives air from an airline tubing running through our tether from a grounded air source. The bag is collapsed and stored within the PVC tube, and inflated upwards when in use. Going into the water with the bag facing upwards does not inflate the bag by mistake as it is crumpled and shoved into the tube. When fully inflated, the bag provides 6kg lift, more than capable of lifting a canon weighing 50 Newtons (equivalent to 5kg).

PVC pipes were chosen as the main component of the lift bags due to its low cost, light weight, and durability. Apart from the heavy-duty hook, the entire Lift Bag is made of plastic and synthetic fabric. This reduces the chances of its weight overturning ***Theta***, and maximizes lift force. Its design is also very simple, making it easy for maintenance and to manufacture spares.

Figure 30: Lift Bag inflating for removing cannon to the surface
(Image by Beth AU)

Since the lift bag is made of plastic and stainless steel, and there are no electrical mechanisms involved, it is both rust-proof and foolproof. Last year's lift bag was still fully functional after being idle for 8 months.

Metal Detector

The Metal Detector is a purchased then modified device, fixed on the bottom left wheel of the ROV, used to identify metal shells from other non-metal debris in Task Three. The device possesses an extremely simple yet effective design which was developed during our 2012 run. We decided to reuse and further develop the design because it is effective and easy to manufacture. An LED light indicates that the detected material is metal, and by driving our ROV close to the item, the lighting up of the LED indicates the presence of metal. The acrylic housing is laser cut and waterproofed, and it is proven to be very robust and reliable in repeated water testing. As a backup option, we will also use manual detection. If our piece of dangling magnet attaches itself to a brick, it is notably a metal cannon shell.

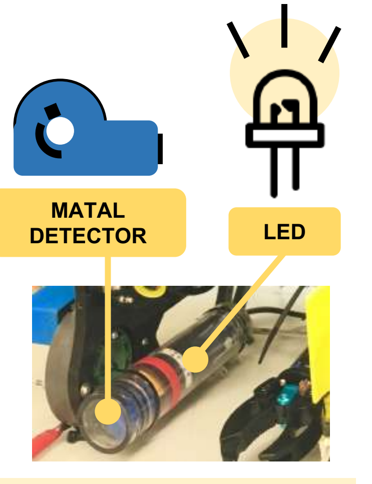


Figure 31: A photo of Metal Detector
(Image by Beth AU)

Temperature sensor

A temperature sensor is used to measure the surrounding water temperature in Task Two. The device is a purchased component that we modified. Originally using USB for power, it now uses a 4-pin waterproof connector and its display is protected and sealed in an acrylic housing.

Design Rationale_15

Figure 32: A photo of the Temperature sensor (Image by Terry AU)

The sensor is mounted on the dock of the Micro-ROV at the bottom of ***Theta*** and the display is fixed on the top of the buoyancy device, positioned before the top mounted camera for a clear view of its reading.

Our initial solution was to use the temperature-measuring device we developed back in 2013. However, the solution was dropped due to its bulk and weight, and the time needed to attach it to ***Theta*** between missions. We favored a temperature sensor as it is lightweight, agile, and simplistic. We decided to directly buy one as building one is not cost effective and not reliable.

SRASR (ScreenRuler) (Designed by Jerry LUM)

Figure 33: A screen capture of ShapeRecognition's interface (Image by Jerry LUM)

SRASR is an application designed to (i)measure lengths on a flat surface and (ii)identify various shapes, suited for measuring the length of the crack (Task One), the size of the cannon (Task Three), and identifying benthic species (Task Two). The application requires a computer for operating the SRASR interface, thus one of ***Theta***'s eight cameras is connected to a laptop through a USB Connection Hub.

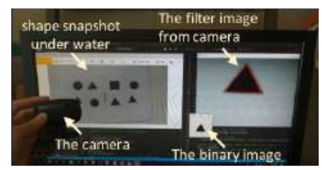


Figure 34: Testing ShapeRecognition's function (Image by Jerry LUM)

SRASR can be separated into two parts - ScreenRuler and ShapeRecognition. ScreenRuler uses the ration an object with a known length to the object seen on screen to determine the length of the unknown object. ShapeRecognition uses OpenCV to convert images into binary form, then transfer the processed images to deep learning modules for shape identification. SRASR is a combination of our previous software - ScreenRuler, and and our new tool - ShapeRecognition. ScreenRuler has been in our inventory ever since its development as a measuring application, and is frequently utilized in both real world scenarios and during missions.

Process & Analysis

A. Challenges

Technical

Figure 35: Preparing a (Prepared by Beth AU)

The biggest challenge we had was maintenance. During our first dry run of the season (7 months after we last competed with our ROV), we immediately realized that one of our cameras had blurry dots in it, which after inspection, turned out to be mould. We resolved the situation through replacing the mouldy camera with a spare. What dawned on us was that, although replacing worn out parts with spares will always be a convenient method, we should start being more aware of parts manufacturing and maintenance, to reduce the risk of rare or expensive parts breaking down just before a competition or other mishaps. Despite being well aware of PLA's water absorbing properties, and having completely sealed them in epoxy, there was still a moisture leak, which probably came from air pockets that were not thoroughly poked while pouring epoxy. This has raised our team's awareness of waterproofing, and that detailed-waterproofing should always be included as a minute yet crucial part in underwater robotics training.

Non-technical

As with our past years, this year's challenge lies again in working with an almost brand new team. New to underwater robotics as they may be, the majority of this year's newcomers consists of 3 years experienced from robotics competition. This gives us a head start in new member training as they are already seasoned robotics users. However, another challenge we face is having to negotiate time and manpower distribution between the VEX Robotics and MATE ROV Competitions. The upcoming VEX Robotics Worlds Championship has already clashed with the Hong Kong Regional ROV Contest, and both mentor and student number has been halved, increasing workload per head. In addition to insufficient manpower, most of our returning members are either in their senior forms, they prepared to public examinations, that also clash with our local competition, making us extremely tight on manpower and leaving us with a low returning-to-newcomer ratio.

B. Troubleshooting

Troubleshooting is essential to the success of Theta. 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 even before encountering any issue, all of our technical personnel are required to have a solid understanding of ***Theta***, extra training and self learning materials are provided for maintenance personnel. To make the process of narrowing down the possible cause more expeditious, historical work orders, inspections, and parts are carefully documented and made easy to go though. Then the process of eliminating possible causes will be initiated, starting from eliminating the obviously false causes. Afterwards, develop possible cause and theories with existing information subsequently distinct the most likely and easy causes. After successfully fixing the component, the solution will be validated and documented for future use.

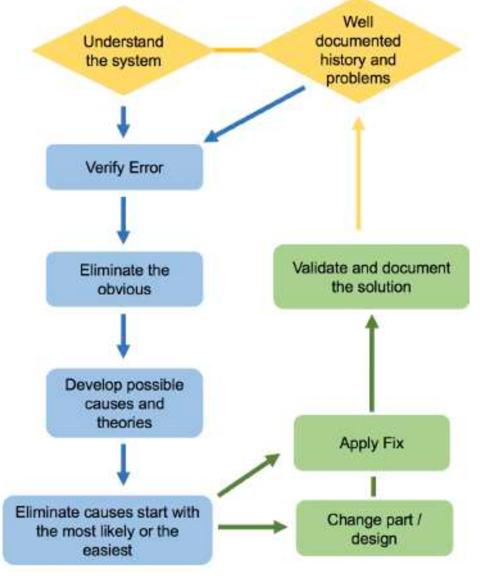


Figure 36: The troubleshooting approach of CMA Underwater Expert Ltd. (Diagram by Terry AU)

We believe that thorough documentation and transparency on information are the key of composing a quick yet meticulous troubleshooting strategies. Thus forming a habit of detailed documentation is one of the focal point of our training for newcomers.

C. Pool Trial

Pool trial is essential to the development of ROV as no result of mere estimation can be as accurate as the result from real world testing. Moreover, no training, reading nor simulation can provide as much valuable knowledge as hand on experiences.

Figure 37: Pool trial in HKIS (Image by Terry AU)

Due to the inconvenience of borrowing Hong Kong International School's (HKIS) pool for pool trial in previous years, a 213cm x 182 cm x 100cm tank is constructed in our lab in 2017. The tank is mainly use for component and buoyancy testing and we do partial trial of the missions as well. We still borrow HKIS's pool for full mission trial due to the size limitation of our tank. Now with the convenience of having our own testing facility, our total time on pool trial is increase substantially this year to 120 hours, about 100 hours in house and 20 hours in HKIS.

Each pool trial is well prepared, well planned and well documented. Meetings are held to reflect on the mistake of the last trial, find aspects to improve and discuss the focus of the next pool trial. Logbook is updated after pool trial, documenting the process, noting down important findings, information and changes made on ***Theta***.

Safety Measures_17

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. CMA Underwater Expert Ltd employee, we 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. These safety measures ensure that all employee work in a safe work environment.

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.

This year, we adjusted the safety checklist (Figure 35), especially, adding about the safety concern of start-up and post-drive the Micro-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, ROV and Micro-ROV
- ☐ Power switch is in place
- ☐ All parts attached to ROV and Micro-ROV are secure
- ☐ Verify thruster shaft seals
- ☐ No conductors incorrectly touching
- ☐ Connectors are fully inserted
- ☐ Make sure the connectors match their labels
- ☐ Protect all spare connectors with dummy plugs
- ☐ Connect the power source to EDCP
- ☐ Ensure the voltmeter value is within operation range (12V-14.8V)
- ☐ Ensure the camera and thruster are good condition

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 (should be around 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 and Micro-ROV are operation completed, power off the vehicle and disconnect all cables or plugs
- ☐ Blow dry the entire vehicle and Micro-ROV
- ☐ Secure all equipment to deck

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

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

CMA Underwater Expert Ltd.

Figure 38: Safety checklist
(Checklist prepared by Terry AU)

C. Safety Features of *Theta*

Mechanical Safety

Thrusters on ***Theta*** come with their own safety covers to prevent the blades from contacting other materials, especially protecting human hands. In accordance with the IP-20 solid particle protection regulation, all thrusters, regardless of brand, should be protected by shrouds with mesh holes no larger than 12.5cm. 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. ***Theta***'s frame is also designed with rounded edges to avoid any sharp or scratch-prone points. All corners of ***Theta*** are rounded and streamlined. The safety of the Micro-ROV is just as important, the thruster come with a mesh that meets the IP-20 solid particle protection regulation, and a 7.5 amp fuse is added on the copper wiring that draws power from ***Theta .***

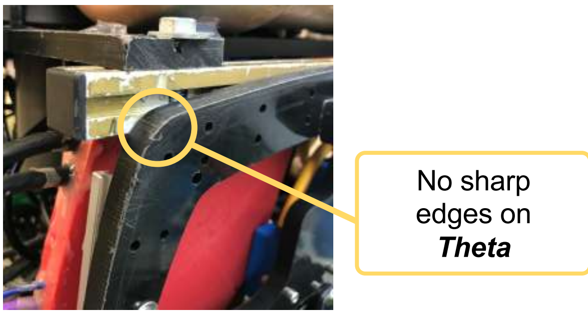


*Figure 39: No sharp edges on **Theta***
(Image by Terry AU)

Figure 40: All propellers are shrouded with 3D-printed shrouds
(Image by Terry AU)

Electrical Safety

A large red emergency stop button is located on our EDCP to cut the power source from the tether to ***Theta*** 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 – 14.8V). It makes sure ***Theta*** is in stable operation. In addition, the emergency switch button switches off all communications and power lines shared with ***Theta***, ensuring complete disconnection.

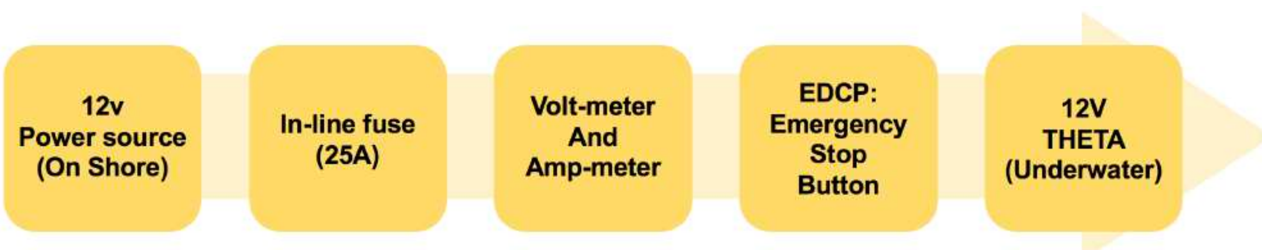


Figure 41: Safety features of the power delivery system
(Diagram by Beth AU)

Through observing the input voltage with the volt-meter and manual operation of the emergency stop button, pilots can detect any hazard that can do possible damage to the electrical system. Figure 41 illustrates the safety features of the power delivery system of ***Theta.***

Tether Safety

Consistent, reliable, and safe power supply is always of top priority. Without good tether management, the cables inside the tether may break, causing leaks and other hazards (worse yet, mid-mission). To prevent this from happening, we have set a protocol standardizing tether storage. During transport by hand, the tether is coiled into the shape of an "8" and hung around the shoulders of a team member, for neat and secure transportation. After each mission, our team members will coil the tether into a reel for storage, 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 offshore. A safety hand guard is used to provide extended protection for both our members' palms and the tether itself.

We had encountered two major mishaps previously - (i)a critical misconnection that led to a power breakdown in our 2nd product demonstration in the 2017 MATE ROV International Competition, and (ii) a crack in our signaling wire during our pool trials, where the leak led to short-circuiting that jumbled up our direction signals. A replacement cable was made.

Since then, we have taken extra care in waterproofing our parts, and securing our connections. For safety, the section of tether closest to the ROV is attached with a tether locker to avoid it from snagging on the ship and threatening the mission.

Figure 42: After taking a safety training session about tether management, newcomers members trying to coil the tether into a real
(Image by Beth AU)

Logistic Safety

During transportation, we can quickly uninstall the core components such as the manipulator, buoyancy board, or subframe, 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 ROV and other equipment.

Assessments and exercises are given to the attendees, who are required to do a brief demonstration to show their understanding by demonstrating 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 ***Theta***, and must be accompanied by mentors or seniors the first few sections.

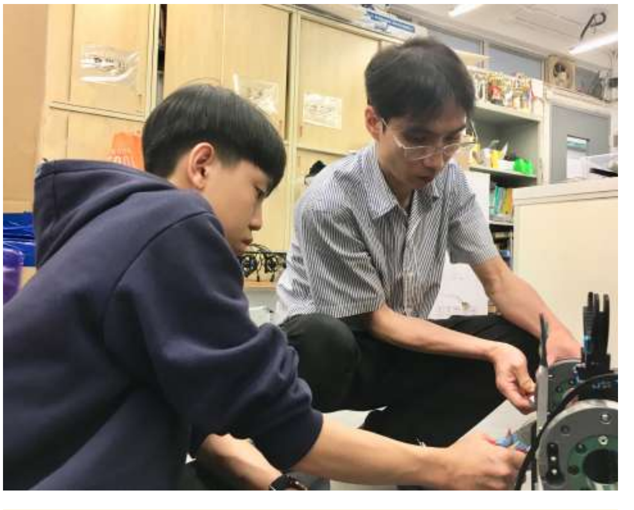


Figure 43: Mr. Cheung introducing the detail safety during building ROV
(Image by Beth AU)

Continuous development of our members is essential and our high mentor-to-mentee ratio ensures that our members get help when needed. Regular pool trails, setup, and disconnecting drills are also conducted. With proper training and standard tests, we can guarantee that our ROVs are controlled and operated by qualified members.

Project Management_20

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 44 shows the organizational structure of CMA Underwater Expert Ltd.

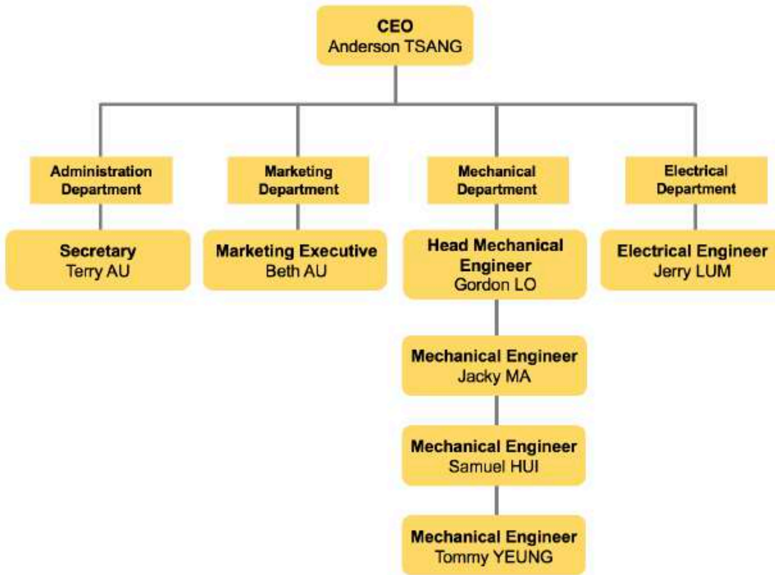


Figure 44: Hierarchy chart of CMA Underwater Expert Ltd.
(Diagram by Beth AU)

B. Scheme of Work

To make sure the current schedule status is known to all employees, a well-designed schedule is devised. CEO 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. Figure 45 shows the detailed role and response for which job.

Schedule								
	2018		2019					
Name	**NOV**	**DEC**	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUNE**
Anderson Tsang *CEO*	Calculate the project budget of ***Theta***	Research on the terrain, economy, and ecosystem of Eastern Tennessee, and on the history and maintenance of Boone Dam Prepare project costing	Job Safety Analysis Safety Checklist	Write Technical Documentation Company Safety Review		ROV testing Practice Sales Presentation	Receive comments from regional from regional contest and improve the Technical Document and Marketing Display	
Terry AU *Secretary*			Prepare project costing Write the Technical Documentation Practice Sales Presentation				Plan the trip for International ROV competition in Kingsport (Air ticket and accommodation)	
Beth AU *Marketing Executive*	Get to know ROV design Design safety checklist	Take and edit photos of ROV, mission tool Design Logo	Design and edit Marketing Display				Recording for ROV testing	Practice the product presentation and product demonstration Prepare documents for transportation Packing all the equipment and shipping to competition venue
Gordon LO *Head Mechanical Engineer*		Build and test cameras Test EDCP	Modify tether Modify and Reinforce manipulator Build and Modify the mission tool: Micro-ROV(Task One), Grout / Fish Fry Container(Task One & Two), Clamps(Task Two), Temperature Sensor(Task Two), Marker Dispenser(Task Three), Metal Detector (Task Three), Lift Bag(Task Three)			Modify the function of components, ROV and mission tools ROV testing	After the regional contest, improve the performance of all mission tools	
Jacky MA Samuel HUI Tommy YEUNG *Mechanical Engineer*		Modify ROV structure Use Sketchup to create initial design of ROV and manipulator	Modify and attach the buoyancy Attaching thrusters on the ROV Make props Waterproof test				After the regional Contest, improve the performance of control system, electrical system, ScreenRuler and ShapeRecognition	
Jerry LUM *Electrical Engineer*		Design and develop the program of control system, electrical system and image recognition and autonomous control (ScreenRuler and ShapeRecognition)				Practice Sales Presentation		

Figure 45: Yearly schedule
(Prepared by Terry AU)

C. Budget

At the beginning of the season, a project budget (Figure 46) was prepared, estimating expenses based on actual expenses from previous years to control cash flow.

This year, we submitted a proposal to CMA Secondary School Education Trust in early September 2018 for asking sponsorship to participate the MATE International ROV Competition if we qualified in our regional contest. Since previous years, we faced limited time and recourses to arrange our whole crew for participating international competition. Finally, CMA Secondary School Education Trust accepted our proposal and willing to sponsor our whole crew for participating international competition in Kingsport. Although we are not competed our regional contest yet. CMA Secondary School Education Trust held a fundraising event feature Mr. Raymond Young's concert, which held on 28 Jan 2019 at the Concert Hall of Hong Kong City Hall. Thanks to Dr. Kai Yum-MA, Chairman of the CMA Social and Community Affairs Committee and Vice President of the CMA, Dr Wang Pun-NG (President of the CMA, and Dr Lop Tak-SHI, First Vice President of the CMA, for supporting our team to step on the international stage for making our dream come true. Once again, thanks for their supporting. Without their help, we cannot make it to the international.

Project Budget (September 2018 - June 2019)

Source	Description			Amount (USD)
Income				
CMA Secondary School Grant	For Regional Competition from CMA Secondary School			1,200.00
CMA Secondary School Education Trust	For International Championship from CMA Secondary School			55,000.00
Expenditure				
Category	Description	Type	Project Cost (USD)	Budgeted Value (USD)
Hardware	**ROV Parts** Sealed Connector, Camera, Styrofoam, Electronic Speed Controllers	Purchased	400.00	400.00
Hardware	**ROV Parts** Frame, Thruster, Tether Cabling, Manipulator Components, Optical Video Transmitter,	Re-used	3,940.00	-
Hardware	**Mission Tools**	Purchased	150.00	150.00
Electronics	**Miscellancous Components**	Purchased	20.00	20.00
Electronics	**Electrical Distribution Control Panel (EDCP)**	Re-used	1,000.00	-
General	**Registration Fees and Fluid Power Quiz**	Purchased	250.00	250.00
General	**Comsumables**	Purchased	500.00	500.00
Travel	**Transportation**	Purchased	350.00	350.00
Travel	**International Chmapionship:** Transportation, Lodging, Meal, Logistics, Registration Fees	Purchased	50,000.00	50,000.00
			Total Income:	56,200.00
			Total Expenses:	56,610.00
			Total Expenses - Re-use/Donations:	51,670.00
			Total Fundraising Needed:	(4,530.00)

*Figure 46: Project budget of **Theta***
(Prepared by Beth AU)

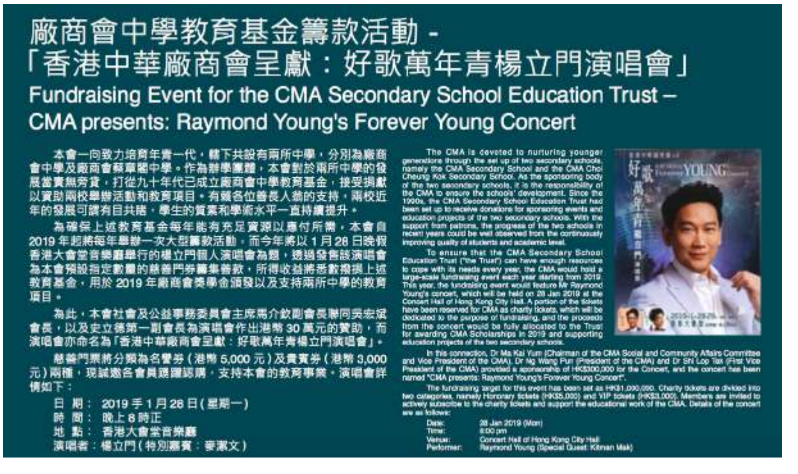


Figure 47: Poster of fundraising event feature Mr. Raymond Young's concert

Thanks to the support from our principal, fellow teachers, and fundraisers, an income of USD 4,200 was obtained to support the MATE ROV competition.

To make Theta more affordable and hit target costs, certain components from our previous ROVs were reused. We decided to re-used some parts from ROV parts and EDCP because it takes 80% costs of Theta. After our professional inspection, there are not damage, so we determine to keep re-used those 2 parts. However, we still spend some costs for maintaining the EDCP, tether cabling, manipulator components and optical video transmitter.

This year, we spent USD 2,245 for purchasing new parts and other expenses with a surplus of USD 1,954. The majority of the expenditure was travel expenses of international competition. The detail project costing is shown on Figure 48.

Project Costing (September 2018 - June 2019)					
Income					
Income	Description	Type	Qty	Cost Per Item (USD)	Total Cost (USD)
CMA Secondary School Grant	For Regional Competition from CMA Secondary School	Donated	N/A	N/A	1,200.00
School Funding	For Regional Competition from CMA Secondary School	Donated	N/A	N/A	3,000.00
CMA Secondary School Education Trust	For International Competition from CMA Secondary School	Donated	N/A	N/A	44,850.00
				Total of Income	49,050.00
Expenditure					
Expenditure	Description	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	385.00
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	390.00
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	20	5	100.00
Styrofoam: 50mm Isopink Extruded Polysyrene Foam Board	3 feet x 6 feet	Purchased	1	40	40.00
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	55.00
Manipulator	Newton Subsea Gripper	Purchased	1	329	329.00
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)	8 for ROV, 12 for separate part	Purchased	20	19.23	384.60
				Sub-total of ROV Parts	4,874.50
Mission Tools					
Task 1: Micro-ROV	Made by: 1 thruster, 1 camera, 1 tether cabling	Purchased	N/A	N/A	50.00
Task 1&2: Grout / Fish Fry Container	Made by: PLA, PVC tube, rubber band, Aluminum Plates and motor	Purchased	N/A	N/A	21.00
Task 2: Temperature Sensor	/	Purchased	N/A	N/A	5.00
Task 3: Marker Dispenser	Made by: Steel and motor	Purchased	N/A	N/A	15.00
Task 3: Metal Detector	/	Purchased	1	10	5.00
Task 3: Lift Bag	Made by: PVC pipes, Waterproof Bag, Metal Hook	Purchased	N/A	N/A	10.00
				Sub-total of ROV Parts	106.00
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	Re-used	1	187.50	187.50
Tether Reel	Storage of Tether	Re-used	1	12.50	12.50
24" Monitor	For Building the Control Panel	Re-used	1	100.00	100.00
8-channel DVR	For Building the Control Panel Re-used from 2017 ROV (Zeta)	Re-used	1	250.00	250.00
Optical Video Transceiver	For Building the Control Panel Re-used from 2017 ROV (Zeta)	Re-used	1	25.00	25.00
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 ROV(Delta)	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	125.00
3D printer Filament: 1kg PLA	Used in Camera, ESCs, Optical Fiber and Styrofoam	Purchased	5	3.5	17.50
Printing	Marketing Display	Purchased	N/A	N/A	30.00
Transporation: Regional Competition	Renting Coach for 2 days (Round Trip)	Purchased	2	212.5	425.00
Regional Registration Fees	Pay to IET	Purchased	1	325	325.00
Fluid Power Quiz	Pay at Active.com	Purchased	1	15	15.00
Regional Registration Fees	Active.com: IET/MATE Hong Kong Underwater Robot Challenge 2019	Purchased	1	125	125.00
				Sub-total of Others	1,190.71
Travel: International Championship					
MATE Registration Fees	Active.com: MATE International ROV Championship	Purchased	1	100	100.00
Transporation	Renting Coach from School to Hong Kong Airport (Round Trip)	Purchased	2	200	400.00
Transporation	Air Fare from Hong Kong to Kingsport	Purchased	10	2,250	22,500.00
Transporation	Renting Coach from airport to hotel (Round Trip)	Purchased	2	200	400.00
Lodging	8 nights for hotel rooms	Purchased	5	2,500	12,500.00
Meal	9 days for 7 employees and 3 mentors	Purchased	270	10	2,700.00
Logistics: ROV	Courier and other delivery cost (Round Trip)	Purchased	N/A	N/A	6,250.00
				Total of Travel Expenses of International Championship	**44,850.00**
				Total Expense of Re-used (ROV) in USD	4,769.11
				Total Expense of Purchased (ROV) in USD	2,240.05
				Total Expenses of Theta in USD	**7,009.16**

Figure 48: Project costing of Sep 2018 – Jun 2019
(Diagram by Beth AU)

	USD
Total Income	49,050.00
Total Expenses (Purchased new parts and travel expenses of international competition)	47,095.05
Surplus of 2018-2019	**1,954.95**

Figure 49: Summary of incomes and expenses from Sep 2018 to Jun 2019
(Diagram by Beth AU)

The surplus will be reserve for next year.

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 2018.

A. 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

Voltage regulation cost us dearly during the prototype phase. As the regulations stated, power supply for the ROV theoretically would be set at 12 volts. Since we use 12 volts R/C car ESCs for onboard electronics we figured that no regulator is needed and our prototype draws its power directly from the power supply. During one of our pool trials, the voltage spiked up to around 15 volts and it overvoltage all of the onboard electronics. Fortunately, most of the components have a reaction mechanism for overvoltage and cut out the current before they are burnt. After this incident, a voltage regulator is added to the EDCP. From this setback, we have learnt a fundamental lesson in the safety factor of engineering. To protect the equipment and operating personnel, a degree of flexibility must be calculated in terms of payload capability, voltage acceptance and other aspects of the ROV. All areas of ***Theta*** is recalculated and tuned to provide the best possible safety, reliability and efficiency.

One of the camera turn mouldy after pool trial and spare was nowhere to be found, moreover there was only one team member is capable of fabricating it. After the incident we decided to produce a comprehensive guide, step by step teaching our member how to fabricate extra cameras.

Troubleshooting has always been one of our greatest defect in the past. As we figured out that our mismanagement of information is the main reason for it, as we did not properly achieved our old record. Thus this year a brand new troubleshooting strategy is made and a new system is in place to categorize and store all of the information and records regarding Theta. A logbook is in use and updated after pool trial, documenting the pool trial process, new findings and changes made to Theta.

Interpersonal

We have further reinforced our strong team spirit and interpersonal skills in this journey. The sophisticated creation of ***Theta*** 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, Gordon Lo, was working on the design of ***Theta***, he provided a lot of insightful input based on his VEX experience, while others members gave critical but substantial comments. This thesis-antithesis process gave us a lot of new hypotheses and directions.

B. Future Improvement

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

Our team certainly has room for improvement regarding talent development and management. As in the past few years, we have been dealing with high talent loss and constant change of blood. And we noticed that it is mainly caused by members usually joining the company after they had several other robotics ventures and is well in the end or near the end of their career. Due to the nature of the project, many outsiders are intimidated, especially for the inexperienced. To tackle the issue, we take on a more initiative approach on recruitment by inviting newcomers of the industry to visit our lab and even provide some hand on experience to ease their concerns. The previously developed e-learning training curriculum had been updated and provide extensive aid for new members.

Other than e-learning, more interactive and hands-on learning style is highly recommended and mentoring is essential throughout the process. A less instructive style of mentoring would be adopted as we noticed that excessive instruction will limit new members creativity, self-learning and problem-solving abilities. As all of our mentors are previous team members, they possess vast knowledge and experience of the field. However, their passion for ROV can be obstructive for new members to develop. To address the issue, a more hand-off mentoring style would be the focal point for our further improvement.

C. Reflection

Anderson TSANG, CEO (Grade 11)

This is my second year bearing the tremendous responsibility of being the CEO of CMA Underwater Expert Ltd. Our goal for the year is the same as ever, to build the best possible ROV we can and to compete with the best at the highest level. The biggest obstacle between us and our goal this year, is that the team was separated into two during the regional underwater challenge, due to clashing with the VEX World Championships. The experience acquired during my first run enable me to make proper planning and execution, we successfully overcame our "insufficient manpower" crisis.

ROVs had always been something special to me, something way bigger than just another school project. It has opened up countless windows for me to learn and see, sometimes even doors of opportunities. Since I will be pursuing my higher education overseas, this will be the last year I am participating in MATE on behalf of CMA. With this special meaning in mind, I will be extra attentive to every single detail, pushing our team to the next level.

Figure 50: Anderson guiding other members for setting up the props in the water.
(Image by Terry AU)

Terry AU, Secretary (Grade 8)

This is my second year participating in the MATE International ROV competition. I was an electrical engineer last year, but the position did not suit me well as electrical engineering is a bit too much to handle for me. Reflecting on last year's experience, I focused more on team communication as it has always been my strong suit, to be more humanistic and considerate when acting as the glue of the team.

This year, I was appointed as the Secretary of CMA Underwater Expert Ltd. I thought it would be an easier job, but I was wrong. I am in charge of a vast majority of administrative and report-related duties. I have to communicate a lot with my teammates regarding scheduling and report information. There were often disputes, but I learnt how to be professional and just carry on with my job.

It's been a great experience for me, not only gaining a lot of technical knowledge but also learning some memorable lessons on communication and team building. I am proud to be a part of CMA Underwater Expert Ltd.

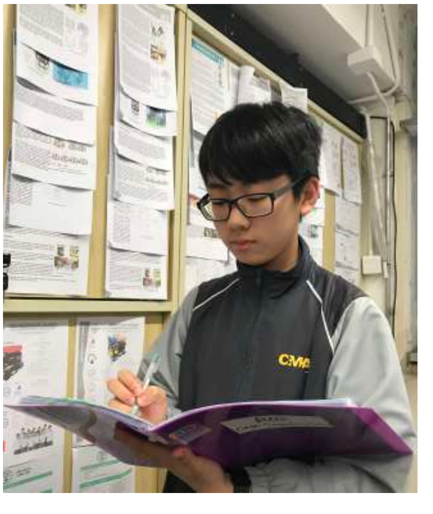


Figure 51: Terry prepare other reference materials for crew to write technical document.
(Image by Beth AU)

F. Reference

1. *Bradski, Gary and Adrian Kaehle (2008), Learning OpenCV. Sebastopol California: O'Reilly*
2. *Morecki, and G. Bianchi, and K. Jaworek(1995), Theory and Practice of Robots and Manipulators :Proceedings of RoManSy 10 : the Tenth CISM-IFToMM Symposium. New York : Springer Verlag*
3. *Bohm H., Jensen V. (2010), Build Your Own Underwater Robot and Other Wet Projects. Hong Kong: Printing International Co. Ltd.*
4. *Information Resources Management Association (2013), Robotics Concepts, Methodologies, Tools, and Applications. United States: Hershey, PA :Information Science Reference*
5. *MATE Center, Underwater Robotics Science. Retrieved March 31, 2017 from http://www.marinetech.org/main/*
6. *Niku, Saeed B (2011), Introduction to Robotics: Analysis, Control, Applications. United States: Hoboken, N.J. : J. Wiley & Sons*
7. *Thierry Peynot, Sildomar Monteiro, Alonzo Kelly, Michel Devy (2015), Volume 32, Issue1, Journal of Field Robotics: Special Issue on Alternative Sensing Techniques for Robot Perception. United States: Wiley Company*
8. *Gianluca Antonelli (2006), Underwater robots: motion and force control of vehicle-manipulator systems, Berlin : Springer-Verlag, 2006*
9. *Bessa, Wallace M ; Dutra, Max S ; Kreuzer, Edwin(2013, Vol.10(9)), Dynamic Positioning of Underwater Robotic Vehicles with Thruster Dynamics Compensation, International Journal of Advanced Robotic Systems*
10. *Lee, Tae-Seok ; Lee, Beom , 2014, Vol.19(1), pp.75-89,A new hybrid terrain coverage method for underwater robotic exploration, Journal of Marine Science and Technology*

G. Acknowledgments

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- Hong Kong International School – for lending their swimming pool for our ROV testing.

Figure 52: Logos of the acknowledged parties
(Prepare by Beth AU)