CMA UNDERWATER EXPERT LTD.

EPSILON

TECHNICAL DOCUMENTATION

Team Members

CEO: Jayden CHAN, Grade 10
Secretary: Victoria LAU, Grade 11
Electrical Engineer: Casipan LUK, Grade 11
Software Engineer: Jerry LUM, Grade 9
Mechanical Engineer: Dicky LEUNG, Grade 11
Mechanical Engineer: Kenny WONG, Grade 11

Mentors

Crystal WONG · Darren CHAN · Jacky LEUNG · Kimberly POOH · Nicole LAM · Queenie YEUNG · Sum CHEN

Supervisors

Man Yuen CHEUNG · Wing CHUNG

HONG KONG

CMA SECONDARY SCHOOL, CMASS ROBOTICS TEAM

Table of Content

Introduction

Design Rationale

Safety Measures

Project Management

Conclusion

Abstract

From identifying and retrieving critical equipment to collecting samples and analyzing data from oil mats in the Gulf of Mexico, or deep-sea exploration in inner and outer space, a tailored Remotely Operated Vehicle (ROV) would be essential.

CMA Underwater Expert Ltd. has been working on perfecting the design and function of ROVs since 2008. The experience provides our company with the capability and technology to support our ROV operating under harsh environment while maintaining its tiny size, making it ultra-portable for CubeSat transportation around the galaxy.

Epsilon is at a small size of 480mm x 510mm x 500mm but equipped with an array of costumed tools, its stability is maintained with its unique integration of 8 Seabotix thrusters to enable horizontal movement and greater velocity. The innovative design of 8 separate mini Electronic Speed Controller boxes reduces the repairing time while fasten the time for troubleshooting. The mature expertise allows us to make use of an optical fiber transmitter box to receive the best signal and better tether management. A manipulator along with a turntable bearing kit and actuator makes ***Epsilon*** functional while its quickly detachable mechanism enhances its portability. ***Epsilon*** utilizes interchangeable payload tools made specifically to the target operating environments. For easy launching and logistics, an all-in-one Electrical Distribution Control Panel is built to connect through onboard electronics to send and receive data for communications.

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

Figure 1: Team photo with all members and mentors in Hong Kong/Asia Regional of the MATE International ROV Competition

A. Aim

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

Our primary objective is to build an integrated underwater robot equipped with the latest technologies at its smallest size. We aim to keep our ROVs tiny, robust and functional. Our second objective is to pilot our professional and sophisticated ROV to accomplish all tasks efficient and meet the weight and size requirements in 2016 MATE ROV Competition.

The following sections devoting to frame design, control system as well as navigation system are directed not only at completing the competition, but to improve human lives in the future.

B. Design Process

In pursuit of creating an ROV which is compatible with our company's standard and the requirement of MATE, we hold a lot of meetings on a regular basis that allow the team members to give their suggestions for the ROV and envision the end result in the design process. Deficiencies of previous ROV are listed out during brainstorming sessions to streamline in the design in order to save time on reviewing mistakes.

	Nov 15	Dec 15	Jan 16	Feb 16	Mar 16	Apr 16	May 16
Design the specification of Epsilon	■						
Design new electrical components	■						
Design new mission tools		■	■	■	■		
Determine the layout of the frame		■	■	■	■		
Determine the vision system arrangement		■	■	■	■		
Assembly of the ROV and		■	■	■	■		
Software development					■	■	
Water testing the ROV and components					■	■	
Troubleshooting of all systems					■	■	
Aesthetic decoration and design							■

Figure 2: The development timeline

C. Overview (Sketches and Draft of *Epsilon*)

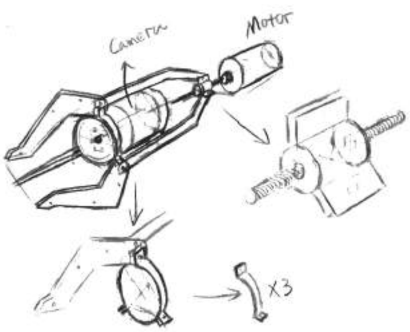

Figure 3: Concept Drawing of Manipulator

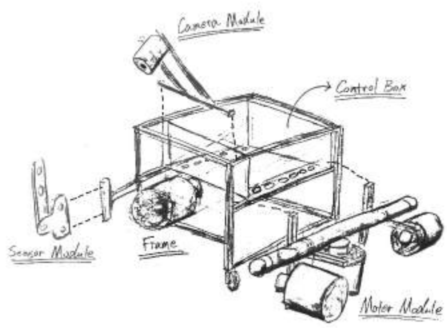

Figure 4: Concept Drawing of ***Epsilon***

Once the design team has validated the concepts through sketches (as shown in Figure 3 and Figure 4), a detailed Computer- Aided Design and Drafting (CADD) model in either using 2D and 3D to demonstrate our initial design, based on need, is fashioned utilizing Google SketchUp.

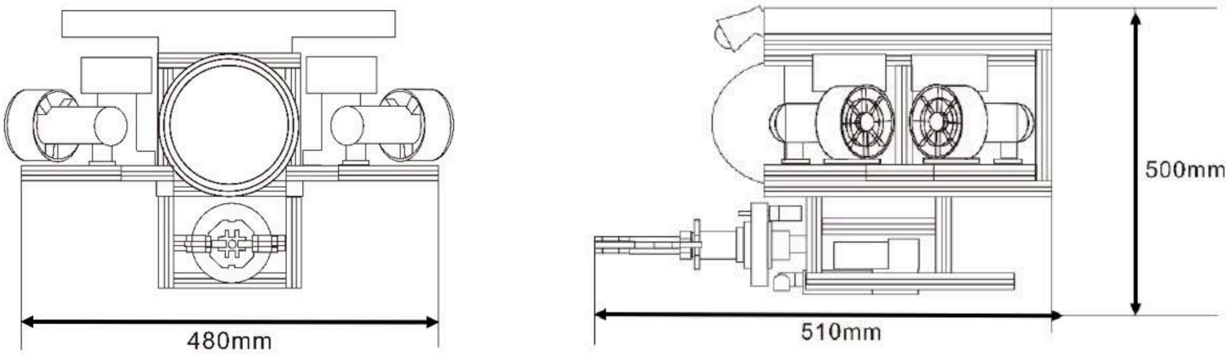

Figure 5: Final design of ***Epsilon***

In order to maximize the efficiency of the design process, we use a CAD model to illustrate the ideas of our ROV, allowing our members to share idea and discuss freely while necessary changes are incorporated until the ultimate design is achieved.

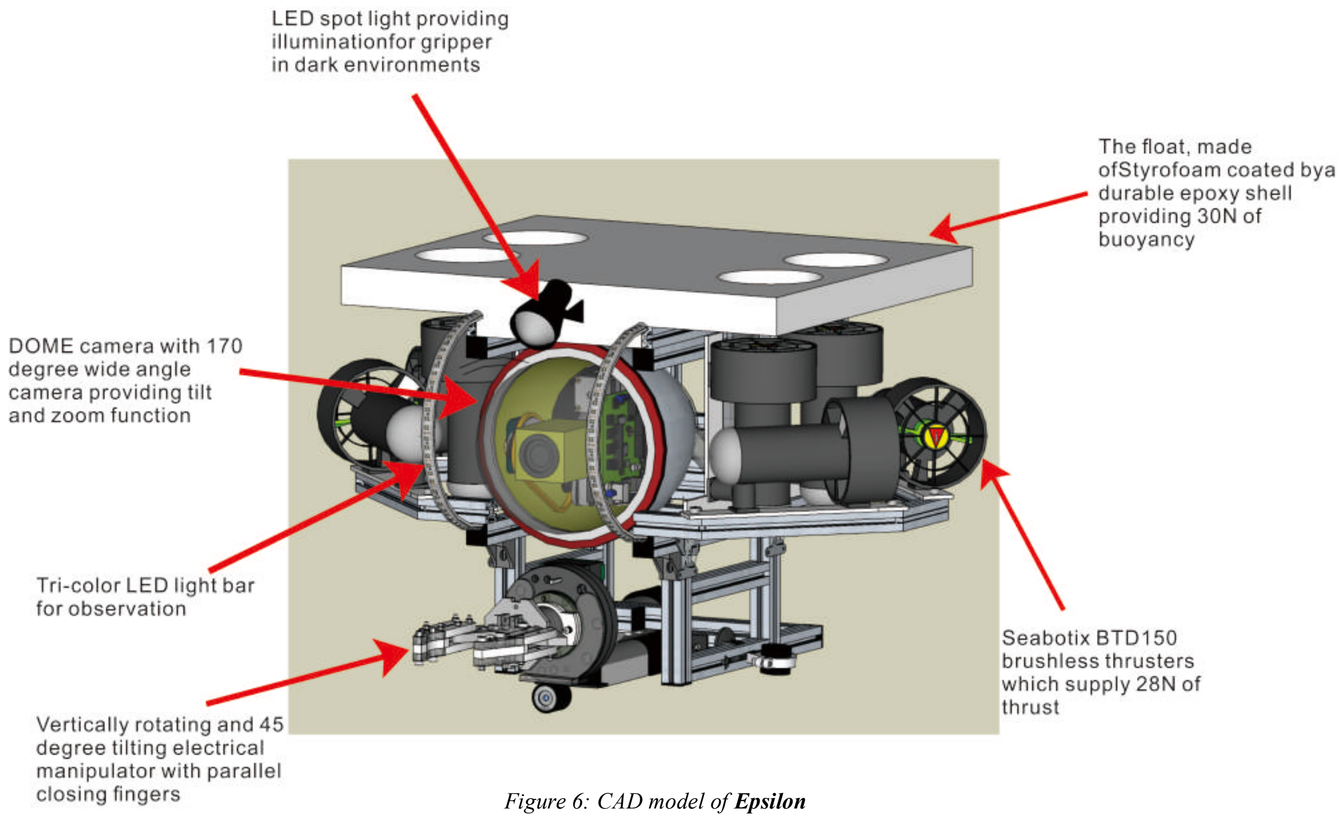

Figure 6: CAD model of ***Epsilon***

D. System Interconnection Diagram (SID)

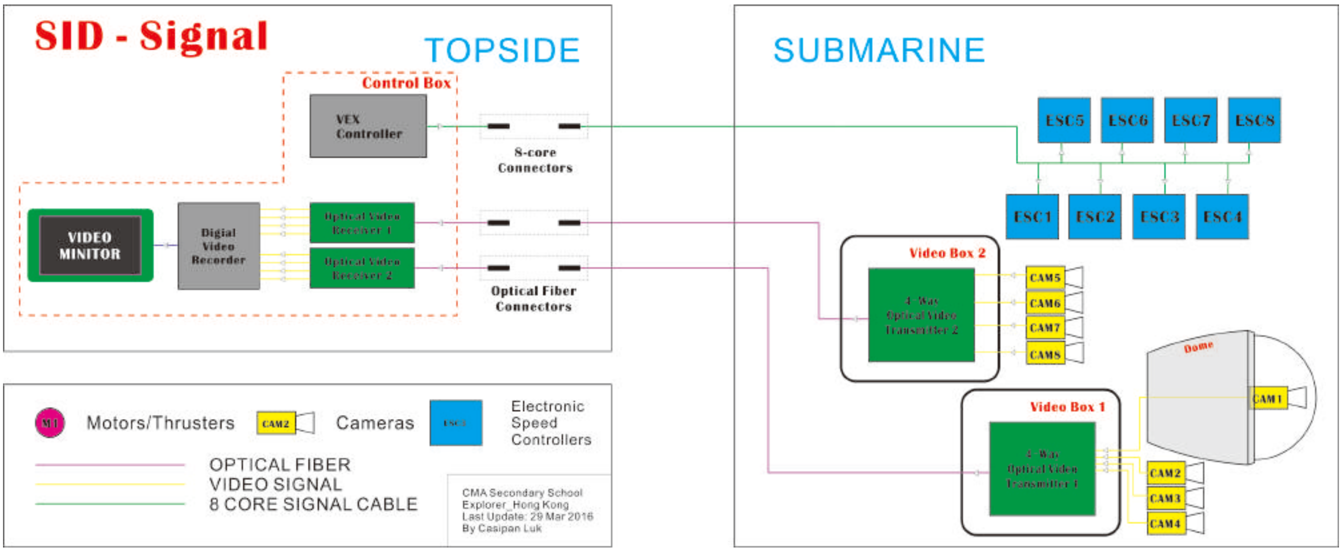

*Figure 7: System Interconnection Diagram (Signal) of **Epsilon***

Using optical fibers to transmit camera signals is conducive to reduce interference as well as to keep ***Epsilon*** 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 its greatest flexibility and stability.

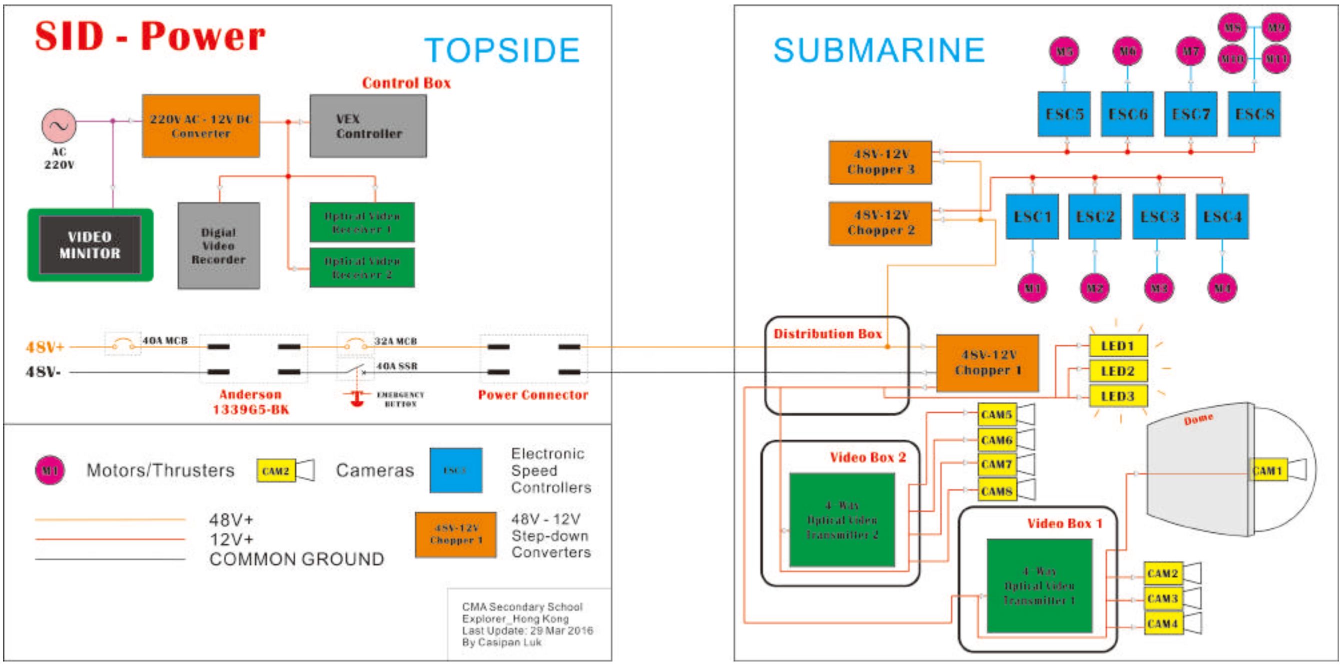

*Figure 8: System Interconnection Diagram (Power) of **Epsilon***

Three 120W 48V to 12V DC-DC converters are used to provide 12V power to the thrusters, LED lights and optical video transmitters. Power consumption of the whole system is limited by 360W which is more energy-saving compared to other similar ROVs.

E. Tether

The tether of ***Epsilon*** is 30 meters long consisting of one 2x2.5mm silicone power cable, one 8-core signal cable, two optical fibers cable and one CAT-5 cable. The 2-core cable is used to provide power to ***Epsilon*** while the 8 core-cable is used to transmit signals. Since we are using the eight digital cameras, two optical fibers are used to transmit camera signals back to the two optical receivers. A CAT-5 cable is used to transmit signal to control the navigation camera so we can adjust the degree of the navigation camera for maximum vision.

	Tether 2015 *(Delta)*	Tether 2016 *(Epsilon)*
Diameter (mm)	27	18
Length (m)	30	30
Total Weight (kg)	10	4
Cables Included	2: Power Cable 2: 8-core Signal Cable 2: Optical Fiber 1: Wire	1: Power Cable 1: 8-core Signal Cable 2: Optical Fiber Cable 1: Wire with Clasp
		

Figure 9: Comparison of 2015 and 2016 Tether

As seen from our previous tethers, of which their power cables inside were broken during past missions, our electrical engineer observed that the old tether is prone to be intertwined during operation. Moreover, it tends to become worn out over a short period of time. This year, silicone is chosen as the main material over polyethylene for it is much lighter than our previous prototypes. Also, the new material can maximize the protection for the tether as it is elastic and tenacious, which can avoid the breaking of cables inside the tether. Since we are going to send our ROV to the outer space and deep sea, the cost of transportation is always of top priority. We need to consider the weight of the tether and ROV. For easier logistics, we decide to reduce the number of cables as much as we can, thus the 2-core power cables are combined into one signal cable for ***Epsilon*** in order to maintain a light weight and reduce thickness.

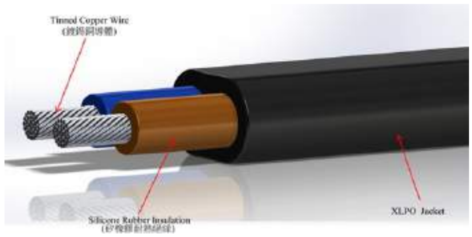

Figure 10: Detail of 2 x 2.5mm silicone power cable

We installed a wire on the tether to pull the entire ROV back to the surface in case ***Epsilon*** is not functioning. The 1.5mm wire is able to pull things up to 200kg. Moreover, all cables are wrapped up by Nylon Woven Braid Wire for safety protection. The wire helps to hold all the cables on the ROV tightly which ensures all cables will not be loosened during operation.

F. Frame

The frame of ***Epsilon*** is made of 2020 Aluminum steel in the dimension of aluminum is chosen over iron for its light weight, rust resistance and durability. A strong frame can maximize the protection of the core components. Aside from the hardness and toughness, aluminum is rust-free and easier to cut. Moreover, it is much cheaper and easier to be installed with other mechanics or electrical components. Focusing on the reconnaissance mission to inner and outer-space, ***Epsilon*** is designed to be the light and small in size because of convenient logistic concern.

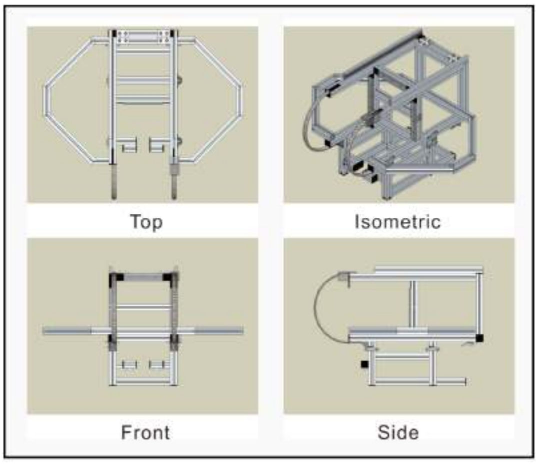

*Figure 11: Overview frame of **Epsilon***

The open frame of ***Epsilon*** provides minimal obstruction and has enough space for the installation of the Electronic Speed Controllers, Optical Fiber Box, Electrical Distribution Box, and Dome camera. All fixed electrical components have been placed at the back of the frame for convenient electrical connection from the tether. Aside from connecting or installation of the components, an open frame enables the easy removal of malfunction components. The front section houses a manipulator, 360° turntable bearing kit, an actuator, and a DOME camera for more stabilized buoyancy and the hemispheric housing aids the streamlining effect while moving in water. Moreover, open frame can easily to installation another aluminum. Last year, we don't have sideways, which makes us difficult to adjust the direction of our ROV quickly. We decided to add 4 more thrusters to enable horizontal movement. An open frame let us install new components quickly, as we only need to add few aluminum bars and screws without the need to design a new frame.

We have been using Autodesk Flow Design to help simulate the performance of the ROV underwater and we keep refining and improving the design to improve the 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, Delta, comes to place. Our robust Delta is now proved to be small but precise, simple but powerful, and able to work efficiently with variable water flow.

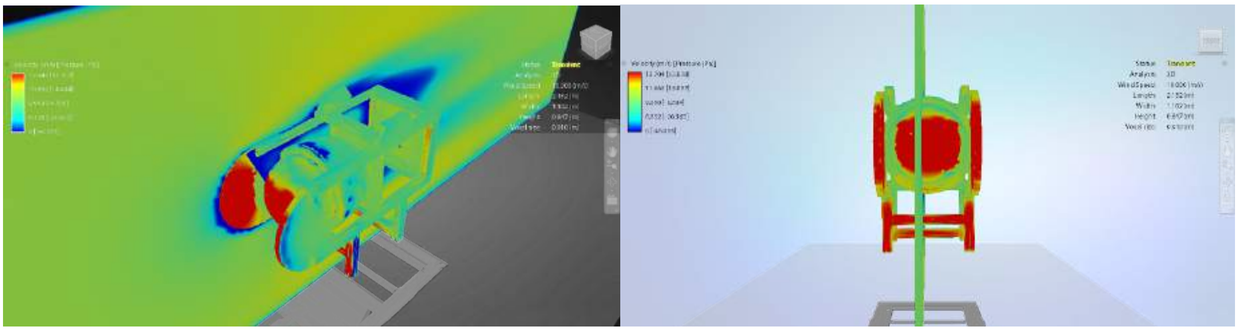

Figure 12: Flow test simulation of ***Epsilon***

The most notable feature of the frame of ***Epsilon*** is it quickly detachable mechanism, which allows effective installation. It can be separated into two sections within five seconds by detaching or disconnecting any other components such as buoyancy board and clip by unlocking a few buckles. This feature enables the clear monitoring of all components during mission and convenient repairing. The quickly detachable mechanism is designed for easy shipping, and to prevent any possible damage caused by logistical issues. Also, every sharp corner of the frame has been attached with plastic covers to prevent them 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.

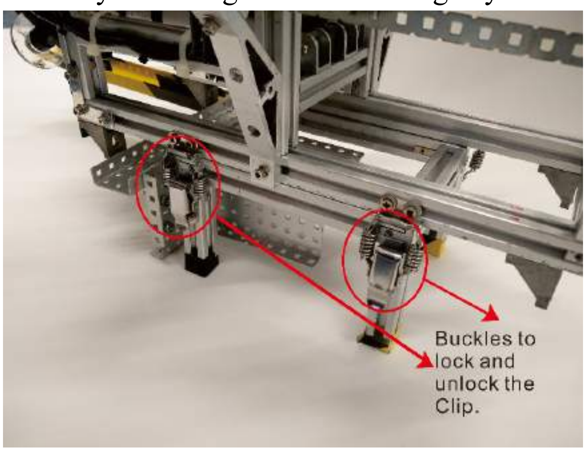

Figure 13: Quick detachable on ***Epsilon***

G. Electrical Distribution Control Panel (EDCP)

The Electrical Distribution Control Panel is the main control system for ***Epsilon*** that gathers the Tether Control System (TCS) on shore, communications, tether connecting to the ROV, and onboard electronics together.

For safety concern and convenient trouble shooting, all onshore electronics are gathered in the flight case for better integration. To activate ***Epsilon***, a 40A and a 32A circuit breaker on the TCS must be closed in order to turn on the power switch, which is a safety feature to minimize the happenings of accidents under operation. In addition to the circuit breaker and the main power switch, there is a power toggle button for all major networking components inside the TCU.

For power concern, two high capacity step down power regulators (48VDC to 12VDC) are used on ***Epsilon*** to power the embedded electrical components. 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 two optical fiber transmitters which are installed on ***Epsilon***. One optical fiber transmitter can only transmit four camera signals; thus two optical transmitters are installed together to send a total of eight camera signals to the optical fiber receivers in the EDCP. The two 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 so as 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 EDCP to send thrusters signals to the mini Electronic Speed Controllers boxes then output power to the thrusters. The 19inch monitor is able to rise up vertically and automatically by installing an actuator and its position can be adjusted for better scanning during operation. Most of the components in the EDCP are re-used to spent more on other electronics and implement it on ***Epsilon***'s hardware for higher efficiency on task completion.

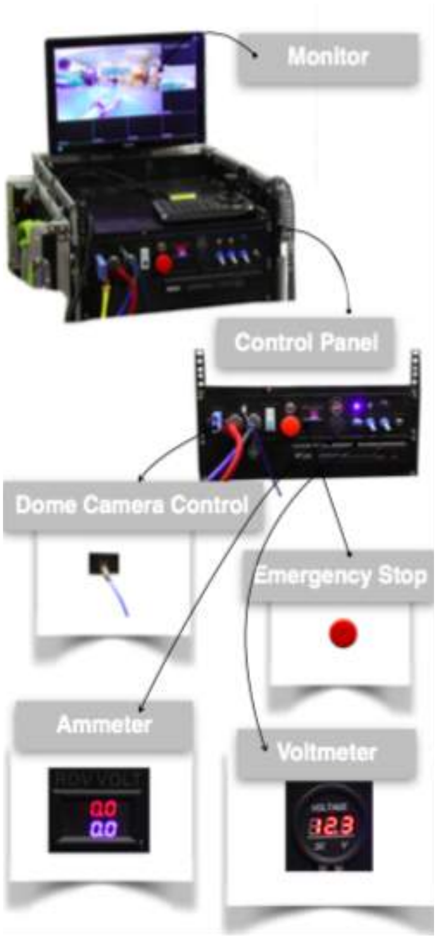

Figure 14: Feature of EDCP

H. VEX Controller Kit

The ROV is controlled by two VEX Controller Kits, with each VEX Controller Kit controlling eight Electronic Speed Controllers boxes, which in turn control the motions of ***Epsilon*** since we are using eight thrusters. Aside from controlling the motion of ***Epsilon***, 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 can be lessened.

I. Electronic Speed Controllers (ESCs)

Our eight SeaBotix thrusters, together with the manipulator, actuator and turntable bearing kit are controlled by eight waterproofed 1060 Brushed Electronic Speed Controllers. These controllers not only provide power to the SeaBotix thrusters, they also connect the VEX Controller and receive signal from it. The ESC can control the moving speed and direction of the motors or thrusters, which can thus provide an effective movement control for the pilot. Since we aim to satisfy the requirement for this year's mission, in which weight is of paramount importance. These controllers are made by acrylic glass, which is much lighter than the previous iron ESC box.

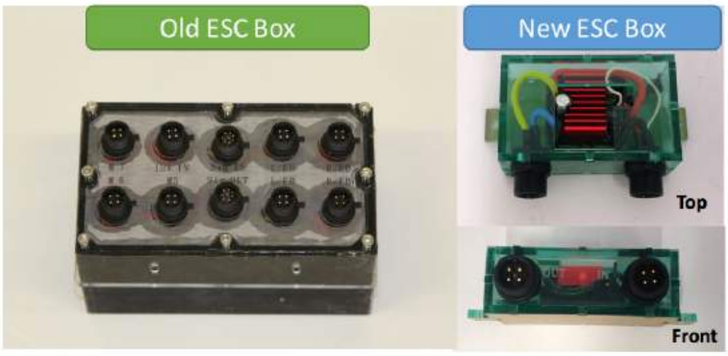

Figure 15: Comparison of the old and new ESC Box

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 serve as an indicator for our pilot that the ESCs are functioning normally.

Modification has been made to our ESCs this year. In our previous ROVs, the ESCs are all 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 its subsequent repair.

This year, we improved the design by individually sealing the ESCs in the acrylic glass box, creating a mini waterproofed housing for each ESC and filled each with epoxy, and then installing them on ***Epsilon***. 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 ***Epsilon***.

J. Thrusters

Epsilon is equipped and operated with eight strong SeaBotix BTD150 thrusters. Four are mounted on 45 degrees directions to allow ***Epsilon*** to have 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 four remaining thrusters are mounted vertically to provide a stronger and quicker levitation movement for Epsilon in the water.

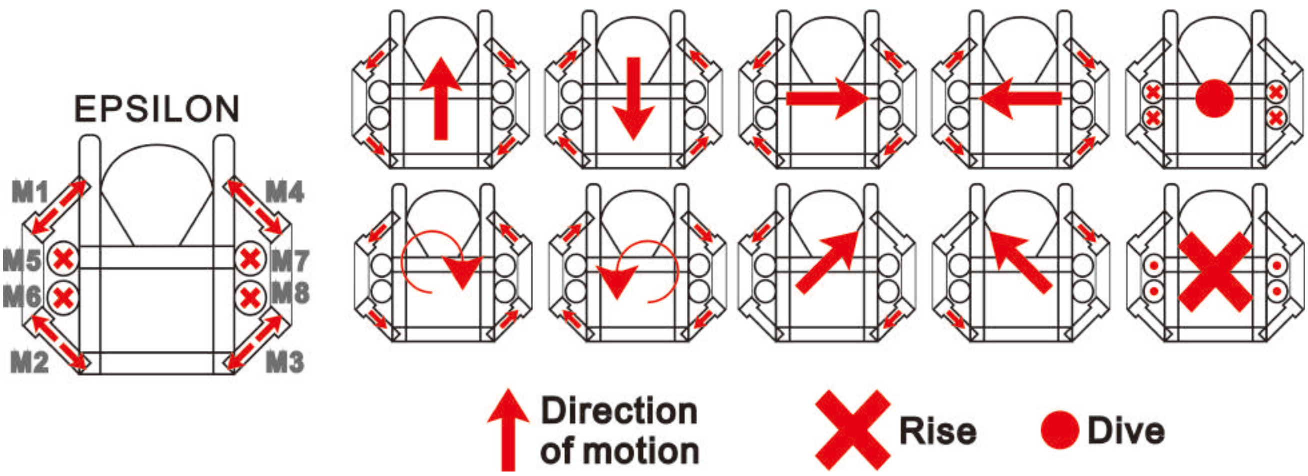

Figure 16: Explanation of ***Epsilon****'s propulsion system*

Each thruster provides a maximum thrust of 28N with a sustainable thrust of 20N. With an operating power at 12VDC and a maximum current at 4.25 A, it satisfies the needs for ***Epsilon***'s power requirement. Each thruster is mounted with kitchen boards that are cut by a laser-cutter machine for easier installation and secure positioning instead of drilling holes onto the frame. A protective cover is covered on each thruster to minimize objects obstruction along with a warning sign to inform our team members to be careful when handling the thrusters.

K. Buoyancy

Epsilon is outfitted with a buoyancy float system specifically designed to neutralize the ROV buoyancy. The buoyancy board is made from Polystyrene as its main material since it is affordable, easy to shape and its peerless low density material to neutralize ***Epsilon***'s weight in the water. Our company tests the buoyancy float by installing it on ***Epsilon***, with all the components installed, and then testing it in a swimming pool. This testing method allows ***Epsilon*** to have more accuracy of buoyancy than estimated calculations.

Figure 17: Styrofoam providing 90N of buoyancy

The weight in water of ***Epsilon***, before the addition of the float, was 90N. The buoyancy board has a dimension of 500mm x 430mm x 45mm, providing a 90N of buoyancy, compensating for the vehicle wet weight and was installed on top of ***Epsilon*** to provide a better buoyancy than placing other sides of it. The shape of buoyancy board is cut by a laser cutter then fiberglassed with bandages and epoxy then sanded to remove any imperfection or any rough surface. A second layer of epoxy is added to smoothen the surface and harden the the buoyancy board to overcome the high water pressure. Its bright red-black color makes our team members to be more alert and aware of safety due to its warm color. Water bottles are added to adjust and compensate ***Epsilon***'s buoyancy if the water density and environment is different, it is used as a weight or an additional float.

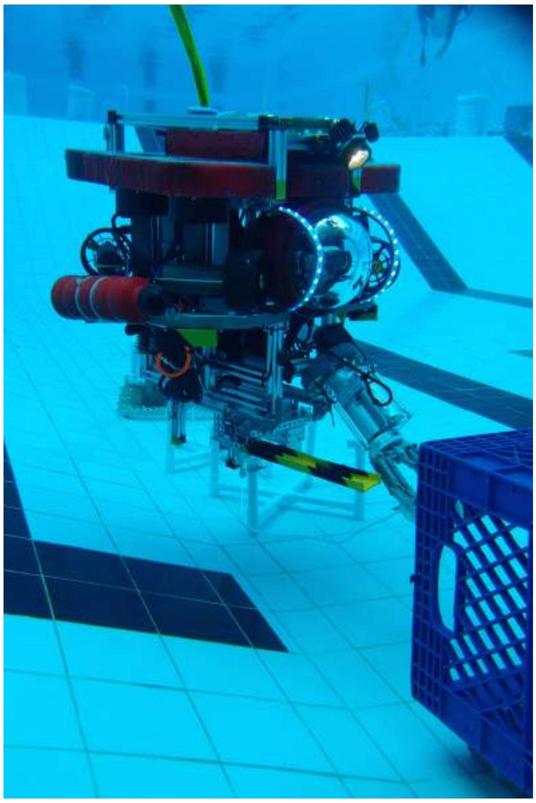

Figure 18: Testing the buoyancy of ***Epsilon*** *in swimming pool*

For the tether, a rope of 15mm dimension foam were attached to ensure that it maintains proper buoyancy, providing easy tether management and increasing operational stability and does not obstruct the movement of ***Epsilon***'s while operation. 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.

L. Software Flow

We have chosen the most accommodative software for the movement of ***Epsilon***, which is EasyC software, is a graphical programmer and has a great command of the software flow, to control the thrusters and manipulator through the Electronic Speed Controllers.

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

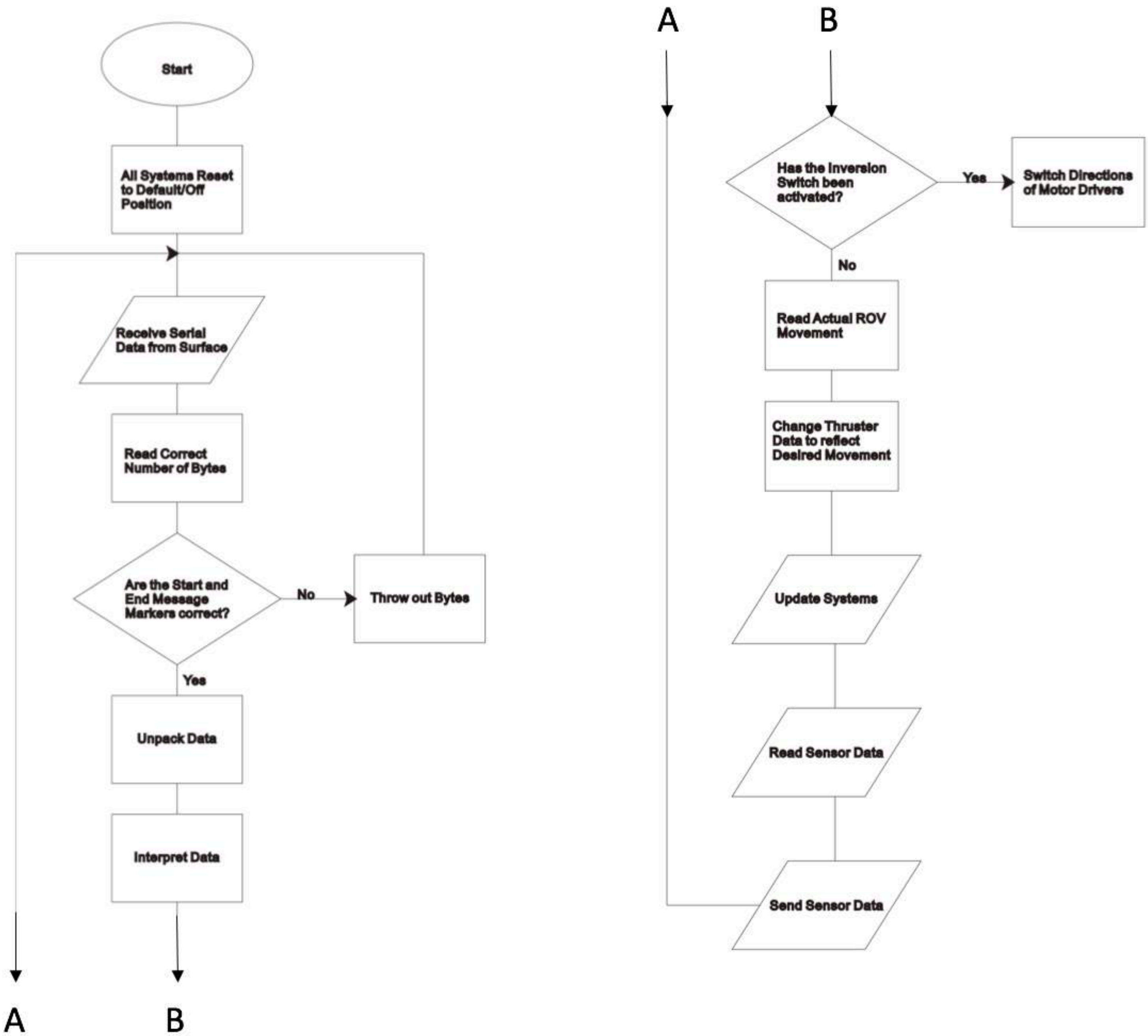

Figure 19: Program flow of ROV control

M. Mission-Specific

Dual Sensor (Temperature Sensor + Pressure Sensor)

A MS583730BA01-50 pressure sensor is installed in the cone-shaped design. This method reduces time without returning to the surface and bring another custom built tool to the seafloor and measure the depth pressure, which is a great assistance during operation. It also reduces our budget to purchase new materials for a new tool and keeping its efficiency level at its highest. Its affordable PVC plastic material is a widely found product and it is easy to be maneuvered. These are the some of our concerns to choose large funnels. Thus, we modified a large funnel into a cone-shaped design and installed the temperature sensor and pressure sensor.

Figure 20: Overview of Dual sensor

A MS583730BA01-50 pressure sensor is a high resolution temperature output allows the implementation of depth measurement systems and a thermometer function without any additional sensor. Pilots will have to bring the Dual Sensor to the seafloor to measure the water pressure and temperature of the venting fluid. The MS583730BA01-50 pressure sensor is implemented with Arduino software to receive data collected from the pressure sensor, and to display it on the mini display of the Data collector.

Figure 21: Overview of MS583730BA01-50 pressure sensor

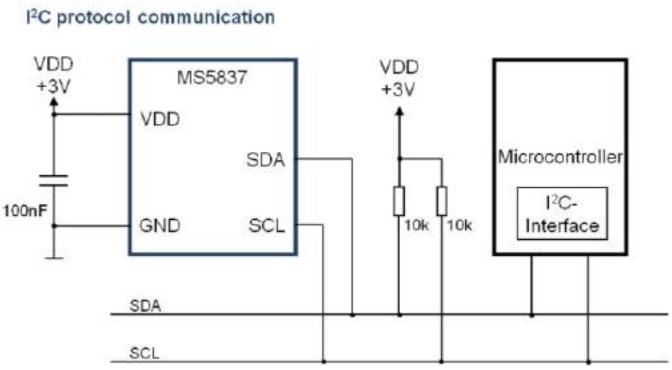

Figure 22: Schematic of MS583730BA01-50 pressure sensor

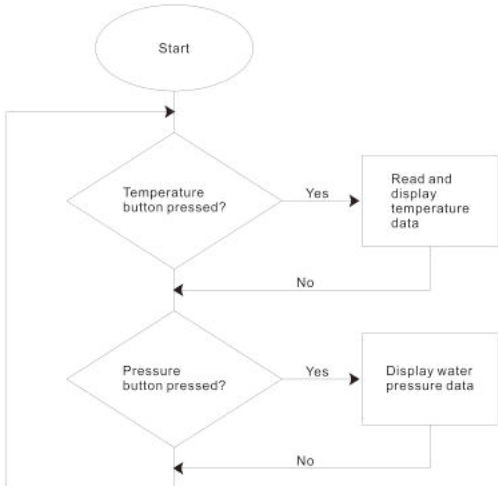

Figure 23: Program flow of Dual Sensor

Clip

Clip is designed to hook the ESC's cable connector and insert it into the port hub in task 1. It is designed and built with VEX aluminum C-channel to hook up the hook on the ESP's cable connector. Two VEX aluminum C-channels are installed to compensate the width of the ESP's cable connector and preventing it from falling when hooked up during transportation. In order to reduce time and increase higher accuracy for pilots, an extended VEX aluminum C-channel is

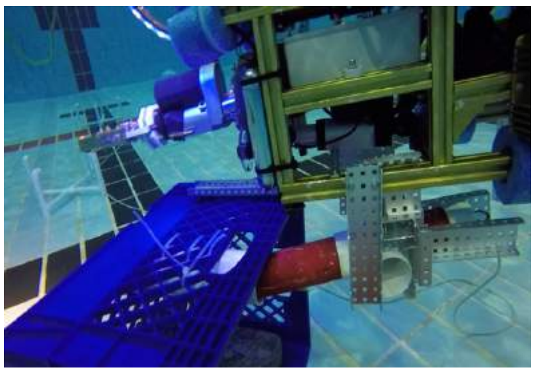

*Figure 24: **Epsilon** using clip for inserting cable connector into port on the power and communication hnb*

installed to use it and pushed against the ceiling of the port hub. Pilots will then not to have to worry about the position of
level in the middle of the water, and have a higher accuracy when aiming the port of the hub. In addition, the clip can act as a backup tool to finish the task if there is any malfunctioning with the manipulator.

Manipulator

Epsilon is equipped with an actuator to open and close the manipulator in a parallel motion. Learning from the groove of a pen's cover, this pushes or pulls the extrusion of the actuator when the motor spins. A crossed bracket is installed on the extrusion and two smaller stainless arms. By pushing the extrusion out, this pushes the two stainless steel arms forward to open the manipulator. The two longer steel arms on each sides of the manipulator keep the manipulator to move in a linear motion when the extrusion is being pushed. The base is screwed with two longer stainless arms of each side of the manipulator to cause the linear motion when the extrusion is pushed. An arc-shaped is also cut in between of manipulator to allow easier gripping for rounded objects. It takes only two seconds for the manipulator to complete the whole set of opening and closing movements with a force of 15 kg. This enables quicker task completion with a higher efficiency. A spring is installed in between of the crossed bracket and the tip of the extrusion for force buffering to prevent the extrusion to be loosed after huge amount of force is pushed or pulled during operation. Stainless steel is chosen due to corrosion-resistant and hard as its feature compared to metal.

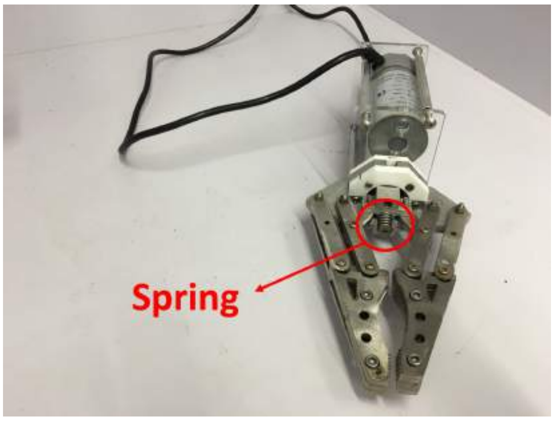

Figure 25: Install the buffer into manipulator

A turntable bearing kit is installed with hinges on the frame ***Epsilon*** with a manipulator installed on the turntable bearing kit, allowing the manipulator to have a 360° clockwise or anti-clockwise rotation. A trailer-made waterproof 393 VEX motor is installed on the turntable bearing kit to turn the tooth gear along with the manipulator in the turntable bearing kit. Another actuator is installed on the bottom of ***Epsilon***, relying on the extrusion to push and pull the turntable bearing kit to incline a 45-degrees vertical motion.

The manipulator' design is focused to tackle a few tasks, such as task 1, the ESP's cable connector is placed on the elevator, which is on the seafloor. Without the actuator, the manipulator is not able to incline 45-degrees vertical motion, enabling to retrieve the ESP's cable, this is reasoned that we have added an actuator to have a new movement to grip the ESP's cable connector more conveniently. The manipulator design has an arc-shaped design to focus on gripping the oil samples in task 2 and other rounded shape objects, this design will have a larger surface to grip the mission objects more tightly, not loosing it and restarting the whole step again. The turntable bearing kit is essential when identifying the serial numbers of the CubeSats as the serial numbers is faced downwards. The turntable bearing kit is used to turn the CubeSats' direction after gripping it and lifting up the seafloor, to let the pilots check after it can be seen through the cameras when the serial numbers can be seen after rotation. Returning the two corals to the surface also relies on the turntable bearing kit to turn the manipulator vertically to grip the horizontal bar of the corals for an ensured grip. Installing the bolts requires a lot of different direction and angles, thus the turntable bearing kit is also essential for this task.

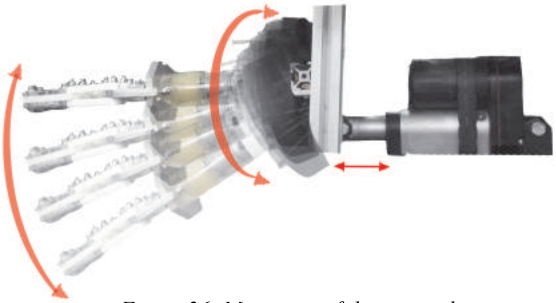

Figure 26: Movement of the manipulator

Cameras

An efficiency operation extremely relies on the use of camera. Aside from observe the ambient under the water. A lot of identification is required for this year's mission such as identify corals.

Last year, we only used four cameras for operation and identification. During the operation, we found that it is hardly to cover all the vision around the ROV. This year, we decided to improved the numbers of the camera. In order to cover every possible blind spot and keep ***Epsilon*** operation steady. Onboard the ROV eight cameras are used for piloting and identification the mission tools. One Dome camera and seven additional cameras with different angles are attached to ***Epsilon*** to achieve maximum field of reduce the blind spot.

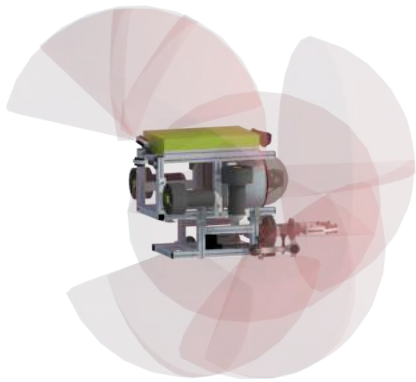

Figure 27: The possible vision of ***Epsilon***

Dome Camera

An efficient Dome camera is a vital component in the design of a successful ROV. ***Epsilon***'s Dome camera made of authentic materials. The camera was originally a surveillance camera in a residential building. After redesigning and adjust, we placed it into a hemispheric housing with an upgraded camera at the front of the ***Epsilon***. It can be remotely controlled through manipulating the control panel.

The Dome camera added with stepper, so that it has a 45-degree vertical movement, which monitor the surrounding area during the mission. This helps pilot can adjust the camera for monitoring the manipulator and surrounding area. For example: During the task 1, we need to inserting the cable connector into the port on the power and communications hub. Without the 45-degree vertical movement, our camera hard to monitor the position of the port.

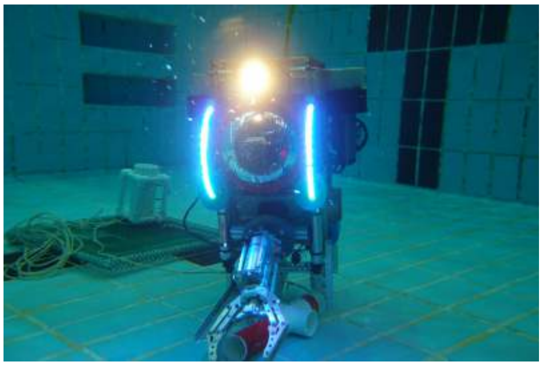

Figure 28: Overview of Dome camera

Side Cameras

ROVs serve to suit human's convenience. The side cameras set on the side of ***Epsilon*** with GoPro mounts and provide sufficient view of effectors. Aside from Dome camera, side cameras are used to monitor the blind spot which the Dome camera can't cover. During the mission such as task 4, the side cameras help to identifying the samples of carols without need to turn ***Epsilon*** back and forth. Beside, side cameras are helped to motion the tether during all mission time, which aims to motion the tether won't tie. If it ties, our pilot can respond quickly. Operation time could thus be lessened while turbulences and disruptions could be prevented for safety concern.

Figure 29: Side Camera testing

LED light Bra and Spotlight

The Dome camera is upgraded to a digital camera withhigher definition of 720 and zooming which helps to provide a clear image in the deep sea, match with LED light bra and spotlight which supply a powerful light source, for identify coral or ambient accurately.

A. Company Safety Philosophy

Safety has always been the main concern of CMA Underwater Expert Ltd.'s. We have the strictest safety procedures, such as, the rigorous safety checklist and the training section for handling or operating the ROVs or any equipment in the lab. These steps can minimal the risk for injuries and provide a safe working environment.

B. Safety Checklist

To ensure proper operation of our vehicles and 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 (start-up, power-on, launching), on-task (in water, lost communication) and post-dive (ROV return to surface, deployment and teardown phase). The presence of at least two operators and the authorization of a senior engineer are needed every time for approval of the list and the 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 (48V – 63V)

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 48V and less than 4A)

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 30: Safety Checklist

C. Safety Feature of Epsilon

Mechanical Safety

Sharp edges are a main safety issue during operation. Therefore, our mechanical engineers deliberately ensure that there is no sharp edge on ***Epsilon***. All corners of ***Epsilon*** are protected with covers.

Besides, thrusters on ***Epsilon*** come with their own safety shield to prevent the contact of the blades to other materials, including the human hands. As the same time, all the moving parts, such as, thrusters are clearly labeled with hazard warning stickers in yellow and black label to our crew from possible hazards. Also, the manipulator of ***Epsilon*** is milled during production process.

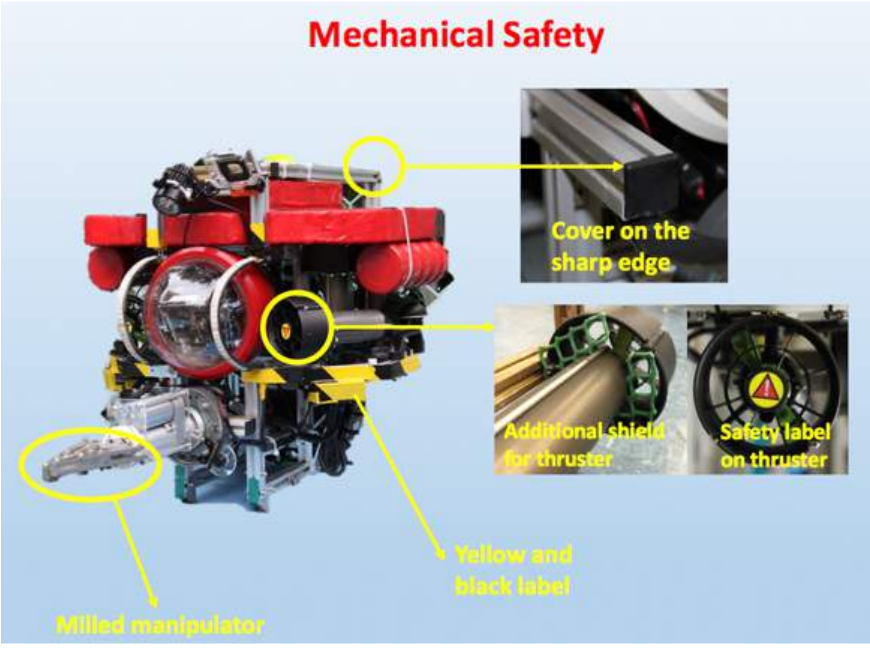

Figure 31: All mechanical safety on Epsilon

Electrical Safety

A large red emergency stop button is located on our EDCP to cut the power source from tether to ***Epsilon*** in case of an emergency situation for our electrical system. Also, we installed 2 circuit breakers. A 40A circuit breaker is placed at the beginning part of the circuit to protect the overpowering of the electrical system. For the 32A circuit breaker, it is a main switch of ***Epsilon***. A volt-meter and amp-meter are installed in control panel to monitor the power source if it is within normal range (48V- 63V). It makes sure ***Epsilon*** is in stable operation.

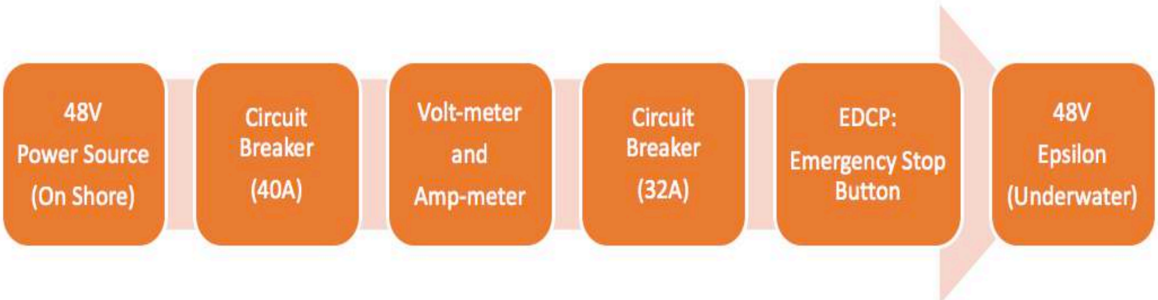

Figure 32: Safety feature of power delivery system

Through observing the input voltage with volt-meter, automatic shut down by circuit breakers and manually operation of the emergency stop button, pilots can detect any hazard that can damage the electrical system. For Figure 32 illustrates the safety feature of power delivery system of ***Epsilon.***

Tether Safety

Safety of our crew members is always of our top priority, and equally important would be a consistent, reliable and safe power supply. Since our electronic engineer discovers that without a good tether management. The cables inside the tether may broken. To prevent this happens, we have designed a company guideline in maintaining the tethers. After each mission, our team members will coil the tether into an 8-shape, rather than circles, to reduce inductance and further pressurization to the cable. This extends the durability of our wires, at the same time minimizing the possibility of power leakage on and off shore.

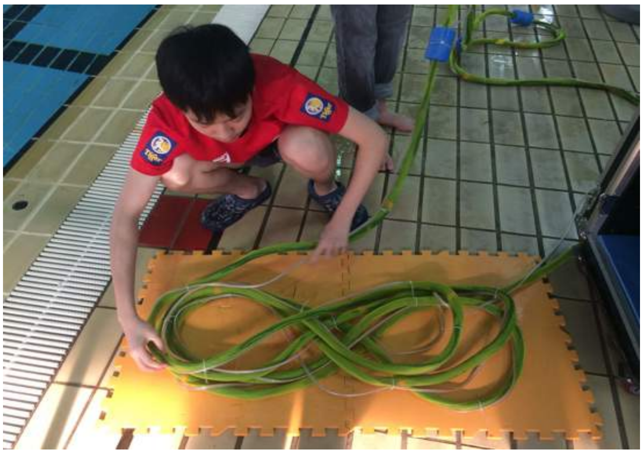

Figure 33: Jayden coil the tether into an 8-shape

D. Training

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

Assessments and exercises were given to attendees, who are required to do a brief presentation to show their understanding by presenting the operating procedures of certain device or component. 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.

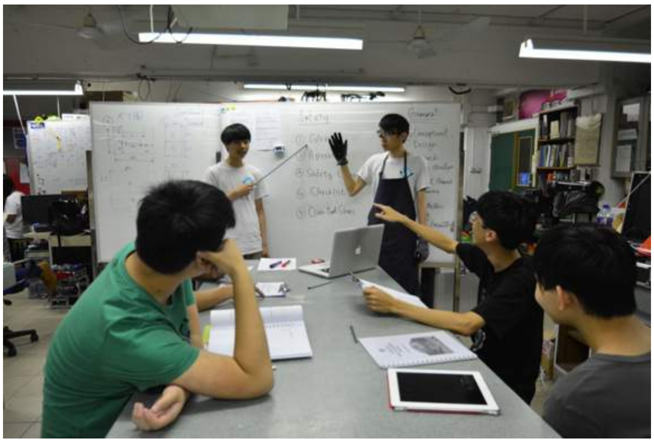

Figure 34: Newcomers and returned members having safety training section

Project Management

A. Company Structure

To provide guidance and clarity on specific human resources issues, a formal organizational structure is implemented. By laying out the company structure, operational efficiency is improved as employees would have a clear understanding regarding the reporting relationships that govern the workflow of the company. Daily production goals are assigned to employees by the CEO daily during the morning meeting with reference to their specific role and duties, and are subsequently reviewed in the debriefing session at the end of each workday. Figure 35 shows the organizational structure of CMA Underwater Expert Ltd.

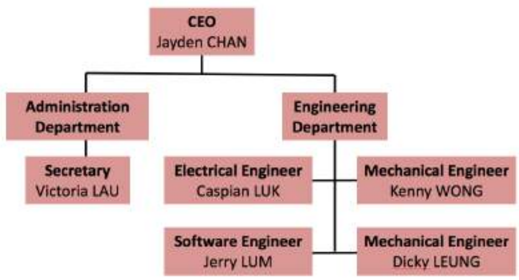

Figure 35: Hierarchy of CMA Underwater Expert Ltd.

B. Scheme of Work

<table>
<tr><th></th><th colspan="8">Schedule</th></tr>
<tr><th></th><th colspan="2">2015</th><th colspan="6">2016</th></tr>
<tr><th>Name</th><th>NOV</th><th>DEC</th><th>JAN</th><th>FEB</th><th>MAR</th><th>APR</th><th>MAY</th><th>JUNE</th></tr>
<tr><td rowspan="2">Victoria LAU
Secretary</td><td rowspan="2">Calculate the budget of Epsilon</td><td rowspan="2">Research about the gulf of Mexico and the Jupiter's moon Europa</td><td colspan="3" rowspan="2">Write the technical document
Prepare the financial report
Write the technical documentation and design the marketing display</td><td rowspan="7">Trail the mission before the regional contest</td><td>Receive the comment from regional contest and improve the technical document and marketing display</td><td rowspan="7">Practice the product presentation and product demonstration

Prepare the document for transportation</td></tr>
<tr><td>Plan the trip for International ROV Competition in Houston (Air ticket and accommodation)</td></tr>
<tr><td>Dicky LEUNG
Mechanical Engineer</td><td rowspan="5">Get to know ROV design

Design the safety checklist</td><td>Design ROV structure</td><td colspan="3" rowspan="3">Design and build the mission tool:
Temperature and pressure sensor, clip and manipulator
Attach the Styrofoam and thrusters on the ROV
Waterproof test
Write the technical documentation</td><td rowspan="3">After the regional contest, improve the performance of all mission tools</td></tr>
<tr><td>Kenny WONG
Mechanical Engineer</td><td>Build camera</td></tr>
<tr><td>Jayden CHAN
CEO</td><td>Use Sketchup to crate initial design of ROV</td></tr>
<tr><td>Casipan LUK
Electrical Engineer</td><td rowspan="2">Discuss the electrical software</td><td colspan="3" rowspan="2">Design and develop the program of control system and electrical system
Prepare the System Interconnection Diagram
Write the technical documentation</td><td rowspan="2">After the regional contest, improve the performance of control system, electrical system and tether</td></tr>
<tr><td>Jerry LUM
Software Engineer</td></tr>
</table>

Figure 36: Schedule of the year

To make sure the current schedule status is known to all employees, the company leadership used a well-designed schedule to assist their decision making. Department heads are delegated to meet different production deadlines according to their respective priority. The schedule is devised, updated and evaluated by the CEO in the morning meeting and debriefing session daily, so as to make certain that the ***Epsilon*** will be ready for the MATE competition according to internal and MATE-specific deadlines.

C. Budget

With reference to the experience gained from previous years, our executive secretary prepared a budget plan for requesting funding this year. We are grateful to receive funding from CMA Secondary School so as to support the Hong Kong regional competition. After securing a place for the International Competition, we kept sending out letters to ask for sponsorships in hopes for covering our possible expenses. Thanks to Tricor Services Limited, we were able to finally receive a funding of USD8650 for ***Epsilon***'s budget. Together with other fundraising events and prize, we have received and raised a total of USD11342.

Since certain components from our previous ROVs i.e Alpha(2012), Beta(2013), Gamma(2014) and Delta(2015) are reused, ***Epsilon*** is made with relatively low cost which greatly helps reduce the overall budget. This year, we only spent USD876.06 for purchasing new parts. Therefore, we have a surplus of USD 294. The rest of budget will be allocated for modification of components, transportation fee and airfare expense of International Competition.

Our team, together with its supervisors and mentors, has contributed an approximate 3,500 hours for planning, designing, building and testing in this project from November 2015 to June 2016.

Financial Report for Epsilon (November 2015 - June 2016)					
Income					
Income	Description	Type	Qty	Cost Per Item (USD)	Total Cost (USD)
School Funding	For regional competition from CMA Secondary School	Donated	N/A	N/A	2,500.00
School Fundraising	For international competition From Tricor Services Limited	Donated	N/A	N/A	8,650.00
Prize Money	IET/MATE Hong Kong Underwater Robot Challenge 2016 Explorer 1st RunnerUp (HK)	N/A	N/A	N/A	192.00
				Total of Income	**11,342.00**
Expenditure					
Expenditure	Description	Type	Qty	Cost Per Item (USD)	Total Cost (USD)
ROV Parts					
20mm x 20mm Aluminum Frame	Re-used from 2015 ROV (Delta)	Re-used	10m	1.54	15.38
SeaBotix BTD 150 Thruster	Re-used from 2013 ROV (Beta)	Re-used	4	769.23	3,076.92
Dome	Re-used from 2015 ROV (Delta)	Re-used	1	12.82	12.82
Tether Cabling	30m (1 for 48V Power Chord , 1 for 8 Control Signal Cores, 2 for Optical Fiber), Re-used from 2015 ROV (Delta)	Re-used	1	N/A	192.31
Sealed Connector	Used in Motors, Electronic Speed Contollers	Purchased	32	2.56	82.05
48V to 12V 10A DC/DC Power Converter		Purchased	3	7.69	23.08
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
Spotlight	Re-used from 2015 ROV (Delta)	Re-used	1	3.85	3.85
Styrofoam	Re-used from 2015 ROV (Delta)	Re-used	1	2.56	2.56
Manipulator Components	Aluminum Plate, Actuator, Buffer, Stainless Steel	Purchased	N/A	N/A	173.07
Aluminum Box	Used in Distribution Box	Purchased	2	51.28	102.56
Optical Video Transmitter	Video Signal to Media Convert	Purchased	2	16.03	32.05
Electronic Speed Controller		Purchased	7	19.23	134.62
				Sub-total of ROV Parts	**3,903.84**
Mission Tools					
Temperature Sensor (DS18B20)		Purchased	1	2.50	2.50
Pressure Sensor (MS5837-30BA)		Purchased	1	3.70	3.70
Clips	Aluminum C-channel	Purchased	1	25.00	25.00
				Sub-total of Mission Tools	**31.20**
Electrical Distribution Control Panel (EDCP)					
Flight Case	Re-used from 2012 ROV (Alpha)	Re-used	1	192.31	192.31
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
LCD Monitor	20", Re-used from 2015 ROV	Re-used	1	141.03	141.03
110V AC to 12V DC Converter		Purchased	1	12.82	12.82
4Channel Network Video Recorder		Purchased	2	32.05	64.10
Minerature Circuit Breaker	32A DC Type	Purchased	1	1.28	1.28
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
Miscellaneous Components	LED Signal Lights, Switches, Wires, Connentors	Purchased	1	12.82	12.82
				Sub-total of EDCP	**871.79**
Others					
Consumables	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	153.84
Printing	Marketing Display	Purchased	N/A	64.10	64.10
Team Clothes	Team T-shirts and sweatshirts	Purchased	13	19.00	250.00
Logistic expense of ROV	Estimated, from Hong Kong to Canada	Purchased	N/A	1538.46	1538.46
Transportation	Flight tickets for mentors and employees	Purchased	13	39.44	512.82
Accomondation	Competition Lodging for 2 Rooms x 9 Nights	Purchased	2	1923.07	3846.15
MATE Fees	MATE Competition Registration	Purchased	1	260	260.00
				Sub-total of Others	**6,753.58**
Total Expense of Re-used (ROV) in USD					**4,058.97**
Total Expense of Purchased (ROV) in USD					**876.06**
Total Expenses of Purchased (International Competition) in USD					**6,625.37**
Total Expenses of Purchased of Epsilon (November 2015 - June 2016) in USD					**11,560.41**

Figure 37: Table of Financial Report for ***Epsilon***

A. Challenges

Technical

Many problems were present when we develop ROV this year. The greatest difficulty lies in refining the manipulator. Last year, we used tappets which are designed on our own. The problem is the extrusion in the manipulator will be loosened after being pushed excessively. This year, we have updated the actuator for the manipulator to adapt to the task. The additional two bomber switches inside the actuator acts as a buffer, which prevents the tappet from tightening or loosening without limits, which will damage our tools and subsequently the functionality of our ROV. This can make sure that the manipulator will be always ready for the mission.

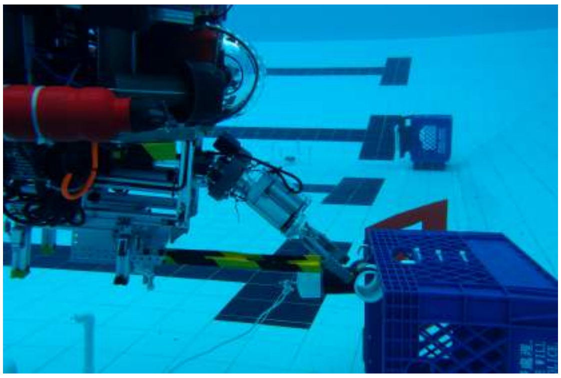

Figure 38: Advanced manipulator for completing the qualification task

Adding a buffer aside, we have also realized that our old manipulator would be as effective as before in completing new tasks for the competition. We have examined different mechanical options and updated fabrication after a series of trial and error. After developing a few prototypes, we have finalized our design of the manipulator in an arc shape, which is ideal for the retrieval of mission-critical equipment for our potential clients.

Non-technical

From the past years' experience, pool trial is of utmost importance to our success in the missions, and it remains to be our biggest non-technical challenge to have a limited pool access. In the hustle and bustle of Hong Kong, it is very difficult for us to reserve an entire swimming pool for trials. The task becomes even more formidable during peak season. Unlike the US, government support in robotics remain minimal, there are even misconceptions that the testing of ROV may put the people who are swimming in the pool at risk. As a result, applications to use public swimming pools for trials are denied. As a high-school-based company, our resources are relatively limited when compared to undergraduates, who often have access to university-owned swimming pools for trials and tests. Testing our ROV in a private swimming pool would not be economically feasible as well, as the cost of renting a swimming pool in a club house would greatly increase the cost of our ROV.

Having access to the product demonstration props and the opportunity to conduct a "wet" run would be greatly beneficial to our mission. To solve the problem ahead of us, we began to contact other regional teams to seek for possible collaboration in dealing with the issue. After a series of exchanges, it is a relief that we are able to borrow the indoor swimming pool of Hong Kong International School (HKIS) for our practices. Their generosity is highly appreciated, which facilitates our testing of the waterproofing of the components of ***Epsilon***, as well as its capability in terms of task completion, durability and overall functionality.

Figure 39: The swimming pool in HKIS used for water trial

The other obstacles we faced is that our mentors and more experienced employees graduated this year in which they have less time to get involved and enforce us on the work of schedule, so we, the comparatively junior ones, are now taking more responsibilities such as the leadership role in tending the new blood of our team.

With the shadowing arranged by our former teammates, we can acquire hands-on understanding of the job in a particular team role, which is beneficial to team productivity.

B. Troubleshooting

Chopper Replacement

Our ROV is equipped with 3 chopper circuits, which are electronic switching devices and circuits used in power control and signal applications that convert fixed DC input (48VDC) to a variable DC output voltage (12VDC) of our ROV directly. As from the experience from our pool trials, there might be a possibility that the voltmeter reading falls into either extreme low or high even the ROV remains idle. Our solution to the problem would be the replacement of burnt chopper(s).

Figure 40: EDCP showing the ammeter and voltmeter for troubleshooting

Firstly, our pilot will disconnect all choppers and connect them to the circuit one by one, at the same time replacing those malfunctioning ones with our spares. With our proactive pre-task, on-task and post-task maintenance, this maintains the functionality and overall stability of our ROV.

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 an invaluable experience that could not be taught in class.

Technical

To aid the buoyancy of ***Epsilon***, an additional of buoyancy is placed near the DOME camera and optical fiber transmitter box to provide the ROV with more upward force. Even if the optical fiber transmitter box's edges are filled with epoxy, water is still able to flow through the optical fiber connector and enter the optical fiber box, deducting the volume of air within and the overall buoyancy and efficiency of ***Epsilon***. During our water trail, we have once encountered seeing no images on our cameras because of the existence of moisture. It consumes a great deal of time to remove the cover and pour the water out of the optical fiber transmitter box. We have discovered that if we fill epoxy on the optical fiber connector at both ends between the optical fiber electronic board and the connector, this will prevent water from entering the optical box and affecting ***Epsilon***'s buoyancy. In order to guarantee no water will flow through the optical fiber connector, grease oil is also added on the connector. Time and human resources is also conserved to maintain the proper functioning of software and hardware on ***Epsilon***.

Interpersonal

We have built up a strong team spirit and interpersonal skills in this journey. The creation of the sophisticated ***Epsilon*** requires countless of time and efforts. As a result, communication and cooperation between teammates is important at every stage of production. We learned to accept others' opinions and listen to others' ideas. Moreover, we are taught to give positive encouragements as well as objective comments in order to perfect our products. When our mechanical engineer was working on the design of ***Epsilon***, he listened to the advice of others that sharp edges should be avoided. Thus, he redesigned the appearance of ***Epsilon*** and became more considerate on detailed parts. We seek advices from supervisors and think of alternatives whenever we face difficulties. Throughout the designing process, we have created a more and more harmonious working environment where everyone is willing to work with others and to respect each other.

D. Future Improvement

Although it was such a great achievement building up a sophisticated ***Epsilon*** with high efficiency and quick detachable mechanism, ***Epsilon*** can be further improved in the future:

Constructing an interface to computerize every movement of ***Epsilon*** and to keep records of the readings is useful for future researches and developments of ROVs. Also, it is crucial for marine observation and maintenance with an interface since it helps to record the tracks and readings of ***Epsilon***. For example, the video recorded through the cameras displaying subsea asset and the outer space could be recorded instantly for future studies. It is much easier and more convenient to chase back the history or check up with the previous data of the ROV for further improvements as well.

In spite of the addition of an interface, there is room for improvements for staff development and mutual communication as well. Everyone in the team has his / her own duty and responsibility. As new members joined the team this year, senior staff is supposed to take care of the junior staff by explaining the company structure, passing on technical knowledge and skills as well as assigning different tasks to them. However, there may be insufficient time for senior staff to meet with the juniors regularly. As we all know, communication is very important for cooperation and synchronization of work at this stage. Therefore, improving the mutual communication and interaction is conducive to the working process and the staff development as a whole.

E. Reflection

Jayden Chan, CEO (Grade 10)

Participating in ROV competition helps to determine my future career. It also enhances me to utilize my skills and knowledge at the best of my abilities in the society and the environment. In the process, I have gained a lot of new technical and interpersonal skills. I am grateful for MATE for providing such practical applications for me to gain experience and preparations for my future career development. During the regional event, our team is able to put our ROV into the test ground among the many other vehicles. This is indeed a golden opportunity for us to better our ROV and develop new designs for faster, more accurate task completion.

Taking the role as the CEO, I am responsible of arranging plans, implementing and integrating the strategic direction of our team, as well as distributing different duties to my team members. It is indeed a new challenge to me since not only do I need to utilize my human resources to the utmost, but also focus on the broader picture and lead the entire organization. To enhance productivity and efficiency, every team member has to work to a fixed schedule and provide additional assistance to those who have fallen behind. In terms of technical knowledge, I have acquired different knowledge, competencies and skills which certainly affirm my career aspirations. To overcome obstacles throughout the development of ***Epsilon*** requires hours, if not days, of reading and researches. These troubleshooting techniques have prepared myself for my future pursuits in the field of Engineering.

*Figure 41: CEO Jaydon setting up for our **Epsilon** before the water trial*

Caspian Luk, Electrical Engineer (Grade 11)

It is the second time for me to join this competition. As a returning member, I have acquired different technical knowledge such as the materials, fabrication, electronics, experimentation, mechanics and physics behind our ROV construction. Making our own tools is a way for us to put theories into practice. I am truly grateful for the help of our experienced mentors, who always guide us to overcome the hurdle ahead. They teach me to investigate different issues from a boarder perspective, for every error there might be a chain of events behind the scene. I gained new skills to avoid problems or find solutions. This is certainly beneficial to my career aspirations as an Engineer. During our team building, I have to share my knowledge to new comers. I need to teach them various basic engineering principles, as well as conducting different hands-on sessions with them. I myself thus have to maintain a schedule and implement it accordingly. Communication with my teammates is of paramount importance this year, especially when we only have limited manpower. I also develop a habit of keeping a mission logbook to remind the team about the problems encountered by the team and our breakthroughs. This has made me more observant and critical when developing solutions on various levels of our ROV production.

Figure 42: Team member are preparing the regional ROV Coopetition

F. Reference

1. *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*
2. *Bohm H., Jensen V. (2010), Build Your Own Underwater Robot and Other Wet Projects. Hong Kong: Printing International Co. Ltd.*
3. *Bradski, Gary and Adrian Kaehle (2008), Learning OpenCV. Sebastopol California: O'Reilly*
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 13, 2015 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. *Steven W. M., Bohm H., Jensen V. (2010), Underwater Robotics Science, Design & Fabrication. Hong Kong: Marine Advanced Technology Education (MATE) Center*
8. *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*
9. *Wang, Xiaoyun (2007), Dynamic Modeling, Experimental Identification, and Active Vibration Control Design of a "Smart Parallel Manipulator". Canada: ProQuest*

G. Acknowledgment

CMA Underwater Expert Limited would also like to thank:

- Principal and teachers of CMA Secondary School for supporting us in all means.
- Man Yuen CHEUNG and Wing CHUNG – our supervisor, guidance us to improve our technical, and non-technical skills.
- Crystal WONG, Darren CHAN, Jacky LEUNG, Kimberly POON, Nicole LAM. Queenie YEUNG, Sum CHEN – our mentors, share their valuable experiences in pervious MATE International ROV Competition to help us improve in technical and non-technical skills
- All the judges of the MATE International ROV Competition and IET/MATE Hong Kong Underwater Robot Challenge

Figure 43: Logo of the acknowledged parties