## 2016 International MATE ROV Competition

## Exploer Class

# TECHNICAL REPORT

Figure 1: Image of Ambassadfor


**CityU Robotic Inc.**

City University of Hong Kong


# AMBASSADOR


Company Member

| | | |
|---|---|---|
| SO TING CHI, OTTO | Year 4 | TEAM LEADER |
| NG WING YAN, LIZA | Year 4 | CFO |
| SZE TSZ HO, SOMETH | Year 1 | TEAM MANAGER |
| CHENG HING ON | Year 4 | CHIEF ELECTRONIC ENGINEER |
| CHAN PETER | Year 2 | CHIEF COMUPUTER ENGINEER |
| LAM WAH SHING, HENRY | Year 2 | CHIEF MECHANICAL ENGINEER |
| LEE SING YU, JOHNAS | Year 4 | CHIEF DESIGNER |
| CHOW PO SUN, MICHAEL | Year 1 | MECHANICAL ENGINEER |
| WONG WUI LEUNG, KELVIN | Year 2 | MECHANICAL ENGINEER |
| LAM SAI LAP | Year 4 | MECHANICAL ENGINEER |
| CHEUNG YIU CHUNG, ALBERT | Year 2 | COMPUTER ENGINEER |
| MAK KO LOK, MC | Year 2 | COMPUTER ENGINEER |
| MOK TSZ LING, JILLIAN | Year 1 | COMPUTER ENGINEER |
| YUE MAN HON, FELIX | Year 1 | ELECTRONIC ENGINEER |
| LAI WING YAN, WILLIAM | Year 3 | ELECTRONIC ENGINEER |
| LEE SEE WAI, SYLVIA | Year 1 | SECRETARY |

Mentor

CHAN, ADRIAN

Supervisor

DR. RAY C. C. CHEUNG

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# I. Introduction
## A. Abstract

Over the years, Humans are curious if there are any other intelligent life forms in the vast Space. With the principle “No life form can exist without the presence of water” in mind, humans put in a lot of effort to search for planets with the slightest trace of water. Eventually, humans found Europa, one of the moons of Jupitar which is suggested to have an ocean underneath its smooth surface.

An Underwater Remotely Operated Vehicle is essential to explore such an unknown place for humans. As such, the Cityu Robotics Inc., developing ROVs since 2012, has developed the new ROV, known as the Ambassador for the investigation of life forms in Europa. As its name suggests, the Ambassador is the ambassador of humans to be in contact with unknown life forms, possibly intelligent kinds, living under the ice crust of Europa.

The Ambassador is built to perform several tasks: 1) investigation of fluid temperature in outer space, 2) identify and transport mission-critical equipment, 3) oil sampling, 4) deepwater coral study and 5) connect and secure cables underwater. What makes the Ambassador stand out from the rest of the ROVs is most of its electronic parts are not within the ROV itself, but are housed inside a control panel above the water instead. Not only the control system will no longer suffer from waterproof problems, the ROV can be replaced in no time if the ROV is destroyed or the hardware is no longer functional, and the mission can continue as usual.

The Ambassador is also one of the few, if not the first functioning endoskeleton-based ROV, instead of being a traditional exoskeleton-based vehicle.

The details of the Ambassador will be shown in this technical report, from the detail of the development process to the design rationale. The Ambassador is the best innovative machine to serve for your underwater missions.

*Figure 2: Team Photo of CityU Robotic Inc.*

# II. Design Rationale

## A. Aims

The ROV is built with the following objectives in mind:

We would like the Ambassador to be highly flexible, such that the frame is modularized and can be easily separated. All changes to the vehicle, including the quality and quantity of the materials used can be conducted with little effort.

The primary aim of the ROV is to conform to the required specifications, as well being able to effectively and efficiently complete the required tasks.

Our company had a limited budget available to us to develop the ROV, as such a secondary but largely important aim was to make the process of designing, building and equipping the ROV as economical as possible.

Instead of building it with high-technology equipment, our ROV is designed to be as economical as possible, while retaining the ability to explore the deepest region of the sea efficiently.

## B. Design Process

Meetings and discussions have been hold among teammates to make the whole development more efficient, by listing everything important, including but not limited to the missions we were going to complete. potential problems that are likely to encounter, and the guidelines we will need to follow during the building of the ROV.

- i) Designing Prototype
- ii) Procurement
- iii) Frame Building and Testing
- iv) Thruster Testing and Installation
- v) Assembly and Testing of Electronics System
- vi) Buoyancy Design
- vii) Software Development
- viii) Final Assembly of ROV

| | Nov 2015 | Dec 2015 | Jan 2016 | Feb 2016 | Mar 2016 | Apr 2016 | May 2016 | Jun 2016 |
|---|---|---|---|---|---|---|---|---|
| Designing Prototype | ■ | ■ | | | | | | |
| Procurement | ■ | ■ | | | | | | |
| Frame Building and Testing | | ■ | ■ | ■ | | | | |
| Thruster Testing and Installation | | ■ | ■ | ■ | | | | |
| Assembly and Testing of Electronics System | | | ■ | ■ | ■ | | | |
| Buoyancy Design | | ■ | ■ | ■ | | | | |
| Software Development | | | ■ | ■ | ■ | ■ | | |
| Poster Design | | | | | | ■ | ■ | ■ |
| Report Writing | | | | | | ■ | ■ | |
| Final Assembly of ROV | | | | | | ■ | ■ | ■ |

## C. Overview

The whole project started off with sketching the frame of the ROV, once we have agreed on the design and the size of the frame, we build one prototype with PVC tube.

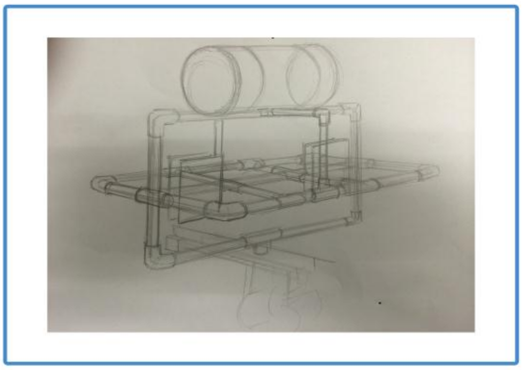

*Figure 3: Concept Drawing of the frame*

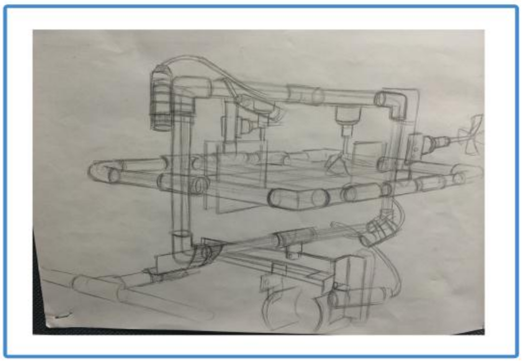

*Figure 4: Concept Drawing of Ambassador*

Although we do not have any figures on the components of the ROV other than the frame beforehand, it is nevertheless a useful draft as we have a better image of the whole ROV. We can thus discuss and determine the most ideal position for every components to be put onto the frame.

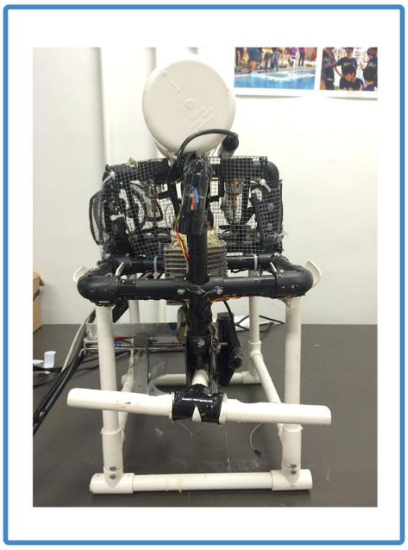

*Figure 5: Front View of Ambassador*

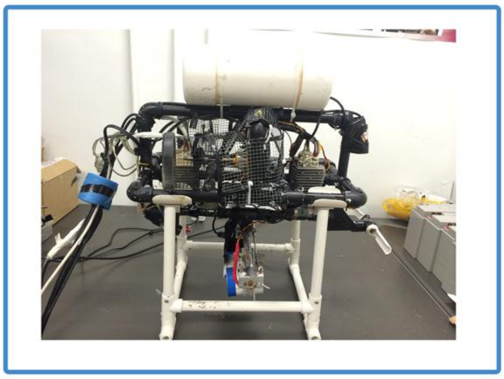

*Figure 6: Side View of Ambassador*

## D. Mechanical Design

### 1. Frame

The PVC frame of the Ambassador is unique even among all ROVs in the tier – since most of the electronics are housed above the water surface, instead of using a frame to house the electronic components stored inside of a cylindrical tube, the frame is used to

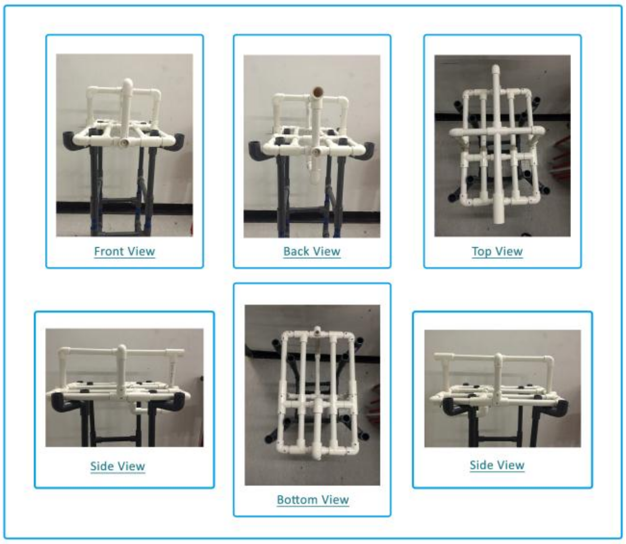


*Figure 7: Overview of the frame of Ambassador*

store all of the mechanical components, sensors and cameras directly on itself. Without a tube, not only the size of the ROV can be dramatically reduced, and water resistances are no longer concerns to the ROV. This also turns the Ambassador from an ordinary ROV in the tier into the very first endoskeleton underwater robot, capable of carrying missions like any vehicles else.

To avoid the risk of damaging the ROV during the long transportation process, the extremely simple design of the ROV could also help reducing the possibility of damaging the ROV as it could be disassembled into parts.

Every component, with rounded corners covered in plastics, are directly attached onto the frame. This ensures that even under non-skilled hands, the ROV can be easily assembled or reduced to limbs. To avoid the risk of damaging the ROV during the long transportation process, the extremely simple design of the ROV could also help reducing the possibility of damaging the ROV as it could be disassembled into parts.

## 2. Thruster

Unlike most ROVs in the tier which are equipped with powerful motors, the Ambassador makes use of XXD 2212 KV1000 brushless Direct Current (DC) motors for the propulsion of the ROV. This motor is usually used by airborne drones only, but we have include this kind of motor to our ROV due to its low price. Using this kind of motor is a relatively new and innovative part of the ROV, since they are capable of providing sufficient thrust for the motions of the ROV, despite them being a motor made for drones.  Due to its design, the motor itself is waterproof in nature which reduces the need of tedious waterproofing during production.

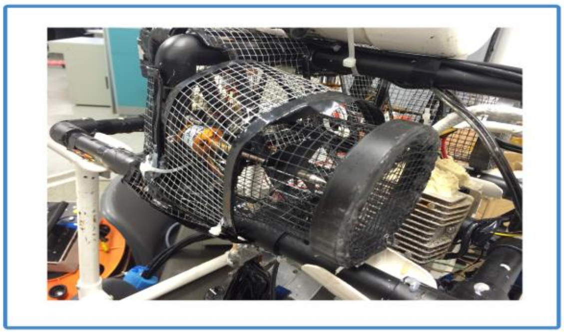

*Figure 8: Thrusters protected with mesh*

In addition, since motor data collected in air is different from motor data collected under water, so we have conducted a series of motor test to test out if this kind of motor is suitable for ROV use or not. The motor test result will be included in the Appendix C.

For horizontal propulsions, since the Ambassador model cannot be driven in the shift-to-left-or-right direction, it experienced minor problems during missions where fine movements in the shift-to-left-or-right direction are required, or when the vehicle experiences turbulence from the sides.  Two motors are mounted at the sides of the ROV, with the blades facing directly to the back, to provide forward and backward motions, or to change directions. Two additional motors are also mounted on the central part of the frame, which is used to provide fine shift-to-left-or-right direction movement.

For vertical propulsions, to facilitate the rising or diving motion of the ROV, two motors are mounted onto the frame of the ROV. This ensures that the ROV can immediately rise, or to provide sufficient thrust to counter the additional weight due to the retrieved samples or equipment.

## 3. Buoyancy

The buoyancy of the ROV is provided by a big PVC cylinder tube. To make the ROV more balanced, weights are added on the bottom of the ROV to counteract the buoyancy. The whole buoyancy system of this ROV is extremely simple, yet effective in its work.

The buoyancy system used is actually a reuse of the ROV our team have made last year. We found that this cylinder design is extremely suitable and matches without frame design.  We simply used two PVC tube covers and combine it with a PVC tube by epoxy.


*Figure 9:  PVC cylinder tube buoyant*

## 4. Electronic Control Kit

The control kit of the Ambassador consists of : (1) A purchased Digital Video Recorder (DVR) Box, (2) A Computer screen, (3) An 8-way joystick, (4) Control sticks which governs either output or vertical propulsions.

The DVR box receives the feed from the cameras underwater through the umbilical cable, which in turn displays the four image feeds onto the computer screen connected to the DVR box equally.

The joystick controls the horizontal (x- and z- ) direction of the ROV. By pushing the joystick towards the 12 o' clock or 6 o' clock direction, the ROV moves forward or backward respectively. Pushing the joystick towards the left or right, the ROV rotates towards the left or the right, by having two motors rotating into the same direction. Should the joystick be pushed towards the corners, one of the motors will spin according to the direction pushed, while the other one will remain motionless.

The two control sticks controls the vertical thrust and horizontal thrust respectively. The vertical thrust controller's default position is set in the middle, while the horizontal thrust controller is set at the zero position. By pushing the vertical thrust controller upwards or downwards, the ROV will be propelled upwards or downwards respectively. The horizontal thrust controller modifies the output of the horizontal motors, which controls the speed of the ROV.

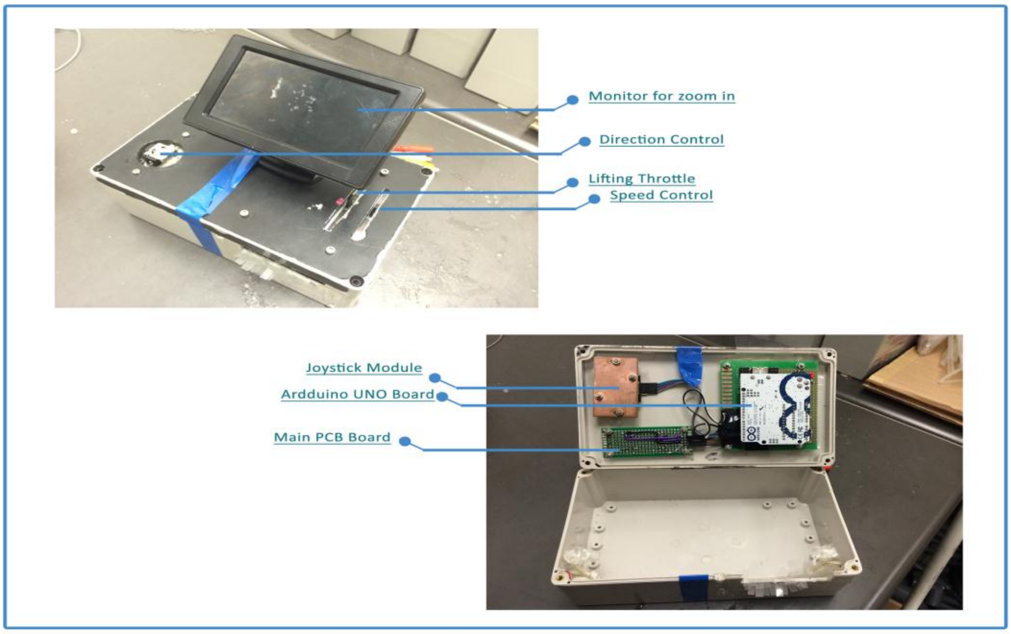


*Figure 10: Key Diagram of the control kit*

The secret for the Ambassador's motor system to work and make the endoskeleton design functional is its customized control system. With a joystick that controls the motors with a program through the resistors instead of buttons, it allows pairs of thrusters to be controlled simultaneously without the need of pressing several buttons to steer the ROV.

One of the features of the ROV is that this kit is custom-made unlike using a PS4 control stick as the control kit. We created the whole control kit from scratch by using a plastic box and solder buttons on it instead.

## E. Electrical Design

### 1. SID

The video signals are transmitted from four cameras to the cameras system allowing for multiple views of mission-specific accessories.

The control signal from the controller to the Electronic Speed Controllers (ESCs) is transmitted using signal wires.

Four 48V to 12V DC-DC converters are used to provide 12V power to the thrusters. One 48V to 5V DC-DC converters are used to provide 5V power to video cameras and sensors. One 48V to 9V DC-DC converters are used to provide 9V power to camera system and control panel.

There are total of ten wires in the tether for signal and power transmitting.

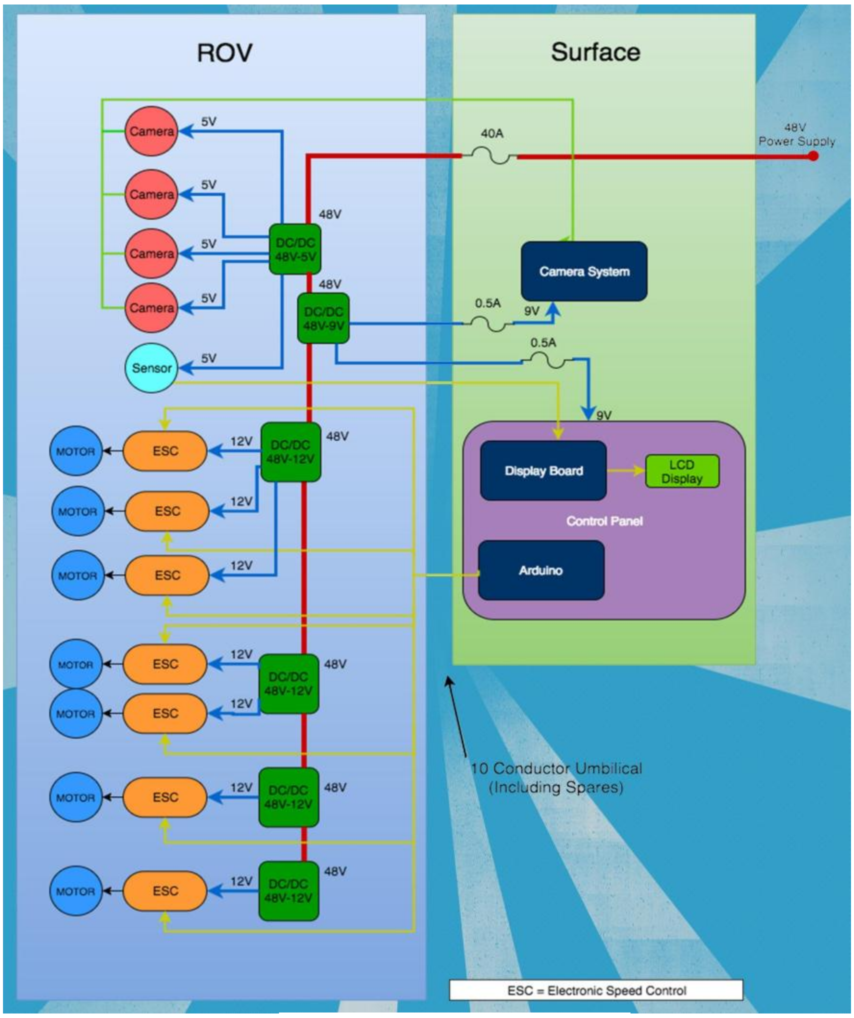


*Figure 11: SID*

## 2. ESC

The motors are controlled by a total of seven 12A Afro Electronic Speed Controllers (ESC). These ESCs provides both signals and current to the motors mounted on the ROV, where the signals came from the custom-made control panel onshore. The ESCs enable accurate control of speed and directions of the ROV through the use of a PS2 joystick and a thrust controlling system mounted on the panel. Since the ESCs are housed within the ROV, additional waterproofing has been added to for protection.

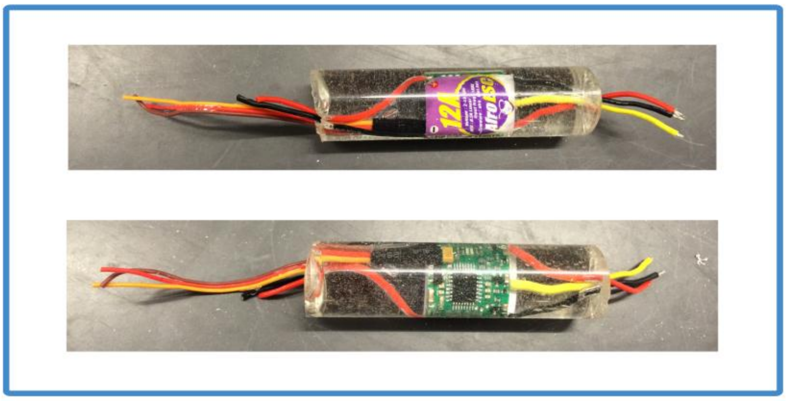

*Figure 12: ESC with waterproof feature*

Unlike most ROVs which uses very powerful ESCs that are meant to withstand high electrical currents, ranging from 40 to 60 Amperes, the motors of the Ambassador are controlled by a total of eight 12A Afro Electronic Speed Controllers (ESC). These ESCs provides both signals and a 12 DC current to the motors mounted on the ROV, where the signals came from the custom-made control panel onshore. The ESCs enable accurate control of speed and directions of the ROV through the use of a PS2 joystick and a thrust controlling system mounted on the panel.

Originally the ESCs are put on-shore and stored within the control panel, instead of putting into water to reduce the need of waterproofing work. However, experimental results shows that signal transferring is inefficient through long cables due to resistance over long wires, and will cause overheating problems as severe as 100 degree Celsius when used on shore, they were now put inside a transparent acrylic tube, and filled the tube with epoxy for waterproofing. They were then mounted onto the frame instead.

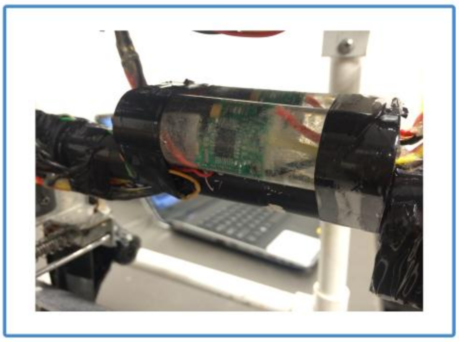

*Figure 13: ESC with waterproofing procedures*

### 3. Arduino UNO Board

The ROV's propulsion system is written in Arduino, and is programmed on an Arduino UNO board. It converts the signals received from the joysticks, and sends them into the ROV underwater through the tether. Not only due to its relatively ease in programming, thanks to the many open-source C/C++ libraries that contains the program needed for the commanding of motors, it also reduces the micro wires that were originally required when compared with PIC controllers, which could avoid tedious wirings and reduces the chance of errors.

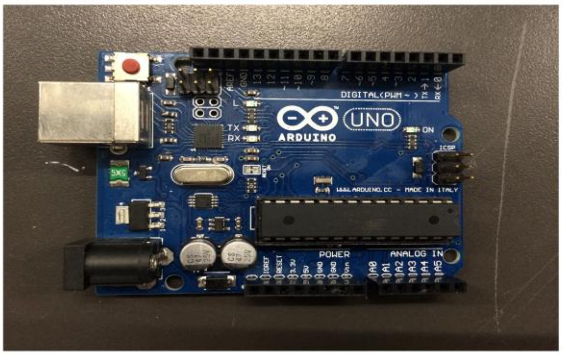


*Figure 14: Photo of Arduino UNO Board*

An interesting quirk of the ROV is the 4 made-in-China 48V-to-12V Direct Current transformers used for the power supply system. Different from other companies that either puts the transformer within the housing or housed on the water surface, which are usually 48V-to-24V professional models made from international companies, the transformers we've chosen are better in several aspects despite its origin of production. The largest merit of the transformer is it being waterproof in nature, which leaves only the wiring part in need of further waterproofing, and can be put underwater without being damaged. It is also suitable for feeding the motors and cameras chosen, which runs on 12V currents, and most importantly it is very economical, yet very reliable and functioned just like any other transformers even under water.

## 4. Software Flow

The Ambassador uses the Arduino software, to control the thrusters and manipulator via the ESCs (Electronic Speed Controllers). The program receives input from the control box and converts the input values to a PWM (Pulse Width Modulation) output value driving the ESCs.

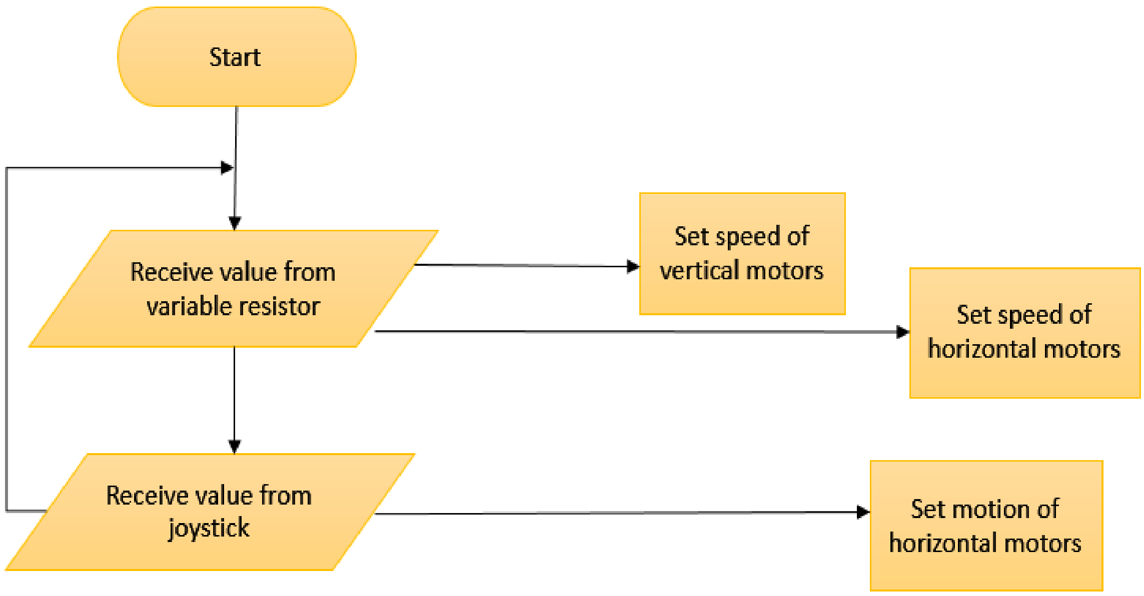


*Figure 15: The ROV motion program flowchart*

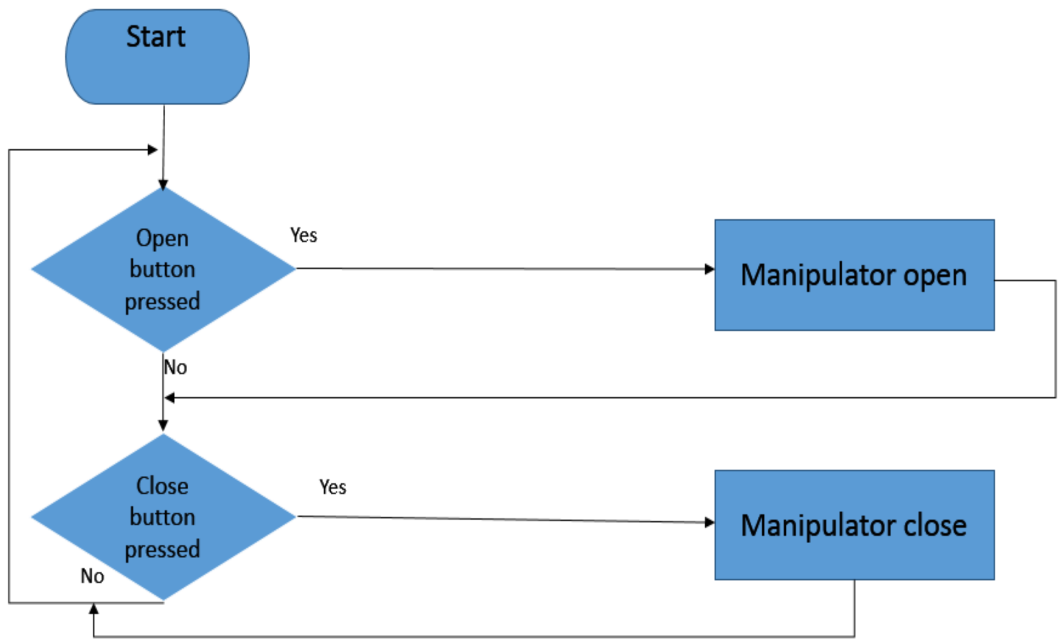


*Figure 16: The ROV manipulator program flowchart*

### 5. Sensor

The mission requirement necessitates the inclusion of a pressure sensor for depth measurements and a temperature sensor to measure the temperature of water at an outflow. It was decided to include a simple directional sensor to assist the operators to allow for improved orientation in returning to the launch location.

The pressure sensor used is an MPX4250AP made by Freescale Semiconductor. It measures from 20-240 KPa this corresponds to actual depth of between 0-15m seawater depth, taking atmospheric pressure into account. The corresponding signal out is an analog voltage between 0.2-4.9v DC. This sensor is temperature compensated with an accuracy of 1.5% over 0-85°C.

The temperature sensor used is the Maxim/Dallas Semiconductor DS18B20. This is a one wire intelligent sensor with a measurement range of between -55°C to +125°C with an accuracy of ±0.5°C between 10°C to +85°C.

The directional sensor used is a Dinsmore compass module 1490 Hall Effect sensor. This device indicates the 4 main ordinate compass directions (North, South, East, West) and the positions between each. The output is digital signal corresponding to the direction the unit is pointing.

The output from all of these sensors is fed into the versatile Microchip PIC16F88. This chip is programmed to digitize the analog output from the MPX4250AP, read the serial one wire output of the DS18B20, and the digital output of the Dinsmore Compass Module. The PIC outputs an RS232C (TTL level) signal that received by a surface display module.

The surface display module is comprised of another Microchip PIC, the PIC16F876A. This device has a 2x16 character LCD display to show the pressure and temperature readings, as well as in 8 LED rose to show relative direction.

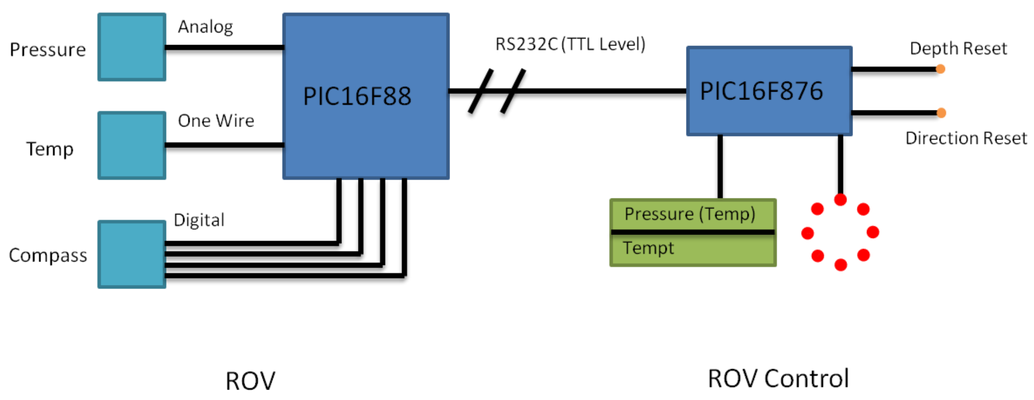


*Figure 17: Electrical Diagram of the sensor*

## 6. Tether

Figure 18: Image of tether

The tether for the Ambassador is about 17 meters long, consisting of one main 48V power cord connected to a 30A fuse, which divides into four thinner cords at the end of the cord, four separate camera signal cables, and two ESC signal wires, held by tapes and fitted with low density Styrofoam tubes to provide buoyancy for the wire.  This ensures that the ROV will not be dragged around and having its movement hindered by the wire's weight. One conductor is used in the tether.

Figure 19: Plugs of tether

The unique positioning of the electronics makes the use of an onboard circuit board system unnecessary. No plugs are present on the end connected to the ROV, instead the wires are directly soldered with the hardware, and are waterproofed by a sheath of thermal casing further covered by epoxy.

# F. Mission Specific

## 1. Cameras

Due to reflection and light being heavily diffused underwater, navigation by naked eye on water surface is difficult, let alone in realistic situations where the ROV might travel in depths that cannot be seen with the naked eye. Cameras are therefore essential for the operator to take a view of the underwater environment.

Four cameras are arranged on the peripheral of the ROV. Each camera contained two main cables, an AV video signal cable and a 5V power supply. Signal cables are connected to a digital video recorder, which can combine the video signal and direct output in a monitor through HDMI or VGA port.

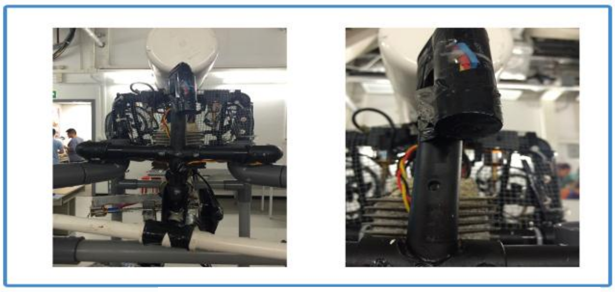

*Figure 20: Front Camera*

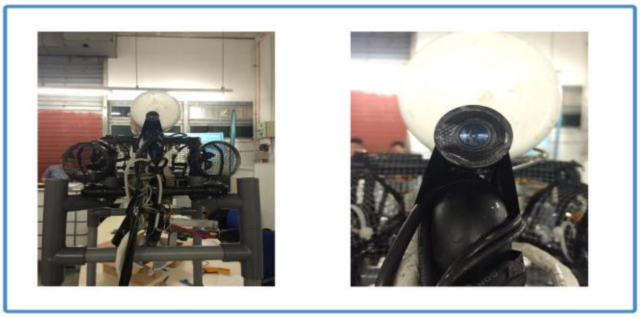

*Figure 21: Back Camera*

Four cameras are arranged on the peripheral of the ROV. Each camera contained two main cables, an AV video signal cable and a 5V power supply. Signal cables are connected to a digital video recorder, which can combine the video signal and direct output in a monitor through HDMI or VGA

The cameras are the eyes of the operator when the ROV is underwater. Not only it allows the operators to take photos for further research, it also provides vision and allows determination of direction during its travel.

## 2. Manipulator

Two manipulators are made and equipped onto the ROV. One of them is equipped at the underside, made specifically for grabbing the ESP, while the other one faces the forward direction and is built to be flexible in motion, to serve multiple purposes

*Figure 22: Image of manipulator*

ESP-Specific

The manipulator is made from a motor mounted directly on the underside the ROV, with one side of a shaft attached on the motor. A calmp made of PVC tubing sliced into halves is attached on the other side of the shaft. By rotating the shaft by the motor, the clamp's width can be adjusted such that it could pick up or release mission-specific objects. The manipulator is made such that it can grab the ESP underwater with relative ease.

Multi-Directional

The manipulator, equipped at the forward direction of the ROV, is regulated by a total of 3 servomotors. The first servomotor is positioned on one end of a PVC tube for controlling the manipulator's vertical position. The second servomotor is positioned at the other side of the tube, which controls where the third servomotor is facing, while the third servomotor controls the clamp to grab desired objects. Unlike the grappler that is fixed in direction which serves for a specific function, it is made with the capability to serve multiple purposes. As such, it is designed to be more flexible and capable of holding small objects and perform fine movements.

### 3. LED Lights

Alongside with the cameras for vision underwater, LED lights are added on the ROV, to provide a higher visibility for the operator underwater, since light can hardly penetrate into the water. Apart from this, LED light can add some decoration to the ROV, thus improves the outlook of the vehicle.

LED is the most suitable lightning source for the ROV, for its high light intensity and comparatively low energy consumption rate. It also has a very small size which could fit on the relatively small ROV.

## III. Safety Measures

### A. Safety Protocol

Like every other companies, safety is what we concerned the most apart from the function of the actual product. Since some construction process of the ROV might be dangerous, some safety measures are needed to protect our members against any potential workplace hazard. Therefore, we introduced a safety protocol for every member to follow, in the following areas.

### B. Lab Safety


*Figure 23: Safety Measures in Lab*

During the construction of the ROV, many potential hazards can occur. Therefore, apart from having warning label on the machine to remind our employee during the usage of the machine, regular safety training is provided twice a year. The training aim to raise the awareness of the employee on workplace safety by various contents for example the basic safety precautions of every single equipment and machine in the lab. For example, wear gloves when handling epoxy, wear goggles when using any kinds of drilling machine. Besides teaching session, we also encourage employee to overlook others when using machines, which can double the efficiency in the safety precautions.

## C. Vehicle Safety Features

Although the ROV is built with PVC tubes and corners, which are safe materials due to the lack of sharp edges, there are still some parts to be concerned about. We've done extensive protection to ensure that the risk of injury is reduced as much as possible. For instance, nuts and bolts are all covered by hot glue after being bolted tightly in place, to prevent exposure of sharp edges to the environment. The propellers, along with the brushless motors are covered by a net of iron mesh as a safety shield, which is fine enough to prevent fingers from entering and prevents contact with the moving parts. All moving parts, such as the motors, are clearly labelled with safety warning labels to warn the users.

*Figure 24: Nuts and bolts covered by hot glue*

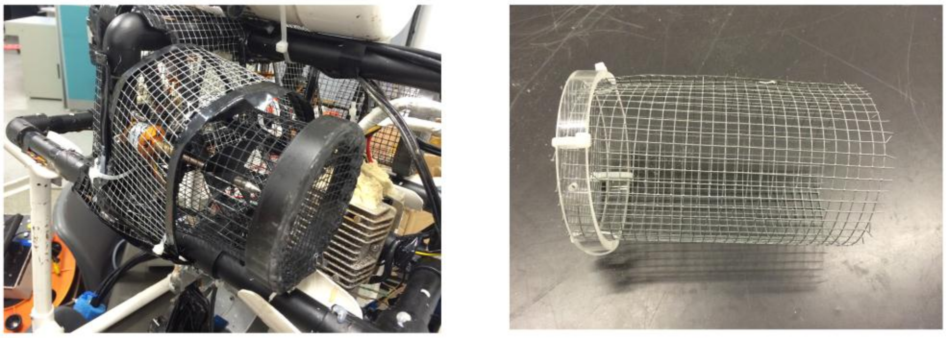

*Figure 25: Thruster with mesh protection*

## D. Operation of Vehicle

A checklist is made for the operation of the ROV, and its completion is compulsory for any users attempting to operate it beforehand. This list protects both the pilot and the crew from harm by ensuring the ROV is free from any abnormalities that are potentially harmful to the crew. Please see Appendix for the detail safety checklist.

# IV. Project Management

## A. Company Structure

In order to maximize the efficiency of the whole project, we have divided our team members to different department according to their specialty.
Members will work on their part and contribute to the project's overall goal as a whole.

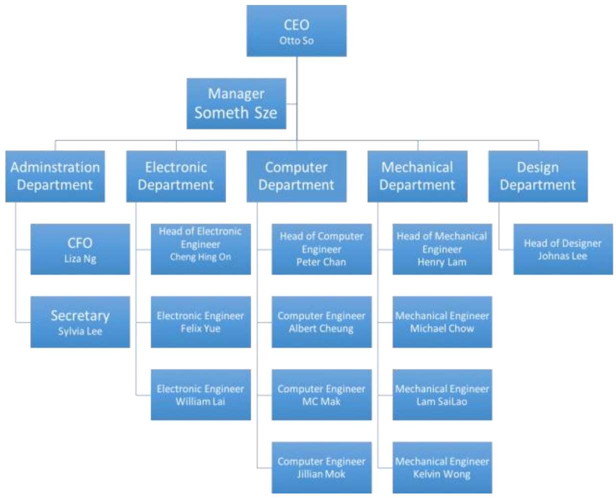


*Figure 26: Diagram of CityU Robotic Inc. Structure*

## B. Project Costing

The costing includes the expenses of our project and the income we get. This year, funding of our company comes from City University of Hong Kong, which has USD$1500 in total. The total cost of the ROV is approximately USD$1440 in which the electronic components like the water servo are the half of the total cost. For the remaining funding, we are going to divert it to the travelling fee and also miscellaneous expenses. The total expense of the project is USD$34,655, and our members, mentors and supervisors have all together work for 720 hours in total. The budget of the project will be included in the Appendix.

| Materials | Item | Unit Price (USD) | Quantity | Typed | Price (USD) | Total (USD) |
|---|---|---|---|---|---|---|
| | | | | | | |
| ROV Body | XXD-2212 KV1000 Brushless DC motors | $0.48 | 4 | Purchased new | $1.93 | |
| | 48V-to-12A Step down transformers | $1.20 | 4 | Purchased new | $4.81 | |
| | ½ -inch PVC tubes | $0.08 | About 3 meters | Purchased new | $0.24 | |
| | ½ -inch PVC Ts | $0.06 | 30 | Purchased new | $1.91 | |
| | ½ -inch PVC angles | $0.06 | 30 | Purchased new | $1.91 | |
| | Copper Couplings | $0.04 | 4 | Purchased new | $0.15 | |
| | 4mm Shaft | $0.27 | 4 | Purchased new | $1.09 | |
| | Model ship propeller | $0.61 | 4 | Purchased new | $2.44 | |
| | M3 Bolts | $0.06 | 50 | Savaged from resources | $3.13 | |
| | M3 Nuts with O-rings | $0.06 | 50 | Purchased new | $3.13 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | ¾ -inch PVC tubes and caps | $0.08 | About 2 meters | Re-used | $0.16 | |
| | Servomotors | $1.45 | 6 | Purchased new | $8.70 | |
| | Tether | $1.56 | About 17 meters | Purchased new | $26.56 | |
| | | | | | | $56.14 |
| Electronics | Light | $1.88 | 20 | Purchased new | $37.50 | |
| | Gyroscope | $6.25 | 2 | Purchased new | $12.50 | |
| | Depth/Pressure Sensor | $65.88 | 1 | Purchased new | $65.88 | |
| | Waterproof Servo | $52.25 | 10 | Purchased new | $522.50 | |
| | 48V-12V Transformer | $24.75 | 4 | Purchased new | $99.00 | |
| | 48V-5V Transformer(Small) | $8.75 | 2 | Purchased new | $17.50 | |
| | Arduino UNO board | $1.25 | 5 | Purchased new | $6.25 | |
| | Afro 12A Electronic Speed Controller | $0.88 | 15 | Purchased new | $13.22 | |
| | Arduino UNO board | $3.19 | 4 | Purchased new | $12.75 | |
| | Cameras | $0.96 | 4 | Re-used | $3.85 | |
| | Variable resistors | $0.06 | 2 | Re-used | $0.13 | |
| | Digital Recorder box | $3.19 | 1 | Purchased new | $3.19 | |
| | Monitor | $62.50 | 1 | Savaged from resources | $62.50 | |
| | PS2 Joystick | $0.03 | 1 | Savaged from resources | $0.03 | |
| | | | | | | $856.79 |
| Control System | Flight Stick | $6.25 | 2 | Purchased new | $12.50 | |
| | | | | | | $12.50 |
| Tool | HandDrill | $25.00 | 2 | Purchased new | $50.00 | |
| | AngleGrinder | $37.50 | 1 | Purchased new | $37.50 | |
| | Soldering Iron | $11.88 | 3 | Purchased new | $35.63 | |
| | Soldering Stand | $7.50 | 3 | Purchased new | $22.50 | |
| | Hand Tool | $3.75 | 5 | Purchased new | $18.75 | |
| | Screw | $0.13 | 100 | Purchased new | $12.50 | |
| | Collect Box for Screw | $6.25 | 2 | Purchased new | $12.50 | |
| | | | | | | $189.38 |
| Flight Case | ROV Case | $187.50 | 1 | Purchased new | $187.50 | |
| | Tool Box | $62.50 | 1 | Purchased new | $62.50 | |
| | Control SystemBox | $75.00 | 1 | Purchased new | $75.00 | |
| | | | | | | $325.00 |
| US Trip | | | | | | |
| Air Ticket | *HK via Los Angeles / Houston // Los Angeles / HK* | $1,056.63 | 15 | | $15,849.38 | |
| | 1st ticket - CX HK/LAX/HK | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | HKD$5934<br>Economy O class HKD5,330 + tax approx HKD604 per adult<br>2nd ticket - AA LAX/IAH HKD$2519 | | | | | $15,849.38 |
| Hostel | 2 students per room<br>21/6-27/6<br>BW WEBSTER HOTEL NASA<br>1st option - 1 KING BED,NONSMOKING<br>2nd option - 2 DOUBLE BEDS NONSMOKING | $0.12 | 8 | | $7,062.00 | $7,062.00 |
| Transportation | Car Rental (21-27/6)<br>Model :Mini van Nissan Quest Auto or similar | $2,035.25 | 2 | | $4,070.50 | $4,070.50 |
| Registration Fee | 2016 MATE ROV - Explorer Class | $242.50 | 1 | | $242.50 | $242.50 |
| Catering | 2 meals per day x 7 days<br>approx. 20 USD per meal | $271.25 | 15 | | $4,068.75 | $4,068.75 |
| Entertainment | Visiting Museum e.g.Houston Museum of Natural Science | $24.25 | 15 | | $363.75 | $363.75 |
| Other | | | | | | |
| Registeration Fee | Registeration Fee for ROV 2016 in Hong Kong | $125.00 | 1 | | $125.00 | $125.00 |
| | | | | | TOTAL | **$34,655.63** |
| Income | | | | | | |
| | School Funding - EDGE, City University of Hong Kong | | | Cash Donate | $1,250.00 | |
| | School Funding - SDS, City University of Hong Kong | | | Cash Donate | $3,125.00 | |
| | School Funding - EDGE, City University of Hong Kong | | | Cash Donate | $10,625.00 | |
| | | | | | **TOTAL** | **$15,000.00** |

# V. Conclusion

## A. Challenges

**Non-Technical**

From the start to the completion of the ROV, the whole process was rather smooth since the design and construction are on schedule. However, despite this, there are still some challenges throughout the development of the ROV. As a whole team, it is difficult for every member to cooperate smoothly with each other. One of the reason is the improper work division among team members during the project due to lack of communication. During regular meetings, we focused mainly on the technical part of the ROV, but since the team was unsure about the progress of other member's work, the project tends to be unable to proceed smoothly during stages of development. Not everyone's capability is fully utilized despite groups focusing on different parts of the building of the ROV were formed. Situations where a small group of team members were required to finish most of the work is not uncommon, which not only puts a lot of pressure to these members, but also further reduces efficiency of the whole team.

**Technical**

Apart from challenges faced in working as a team, during the building of the ROV, difficulties also emerged. For example, we would like to use carbon fibres to build the frame of the ROV, but due to transportation delay, we cannot get the requested material on time. PVC tubes are used to build the structure instead. In the preparation work, we should've planned ahead or prepare a substitutional material for the construction of the ROV.

## B. Lessons Learned and Skills Gained

The CityU team this year employed a large amount of new members to support the development of the team. With the team consisting of mostly members that has little knowledge or skills related to their tasks, work cannot be shared between members easily, which puts a lot of strain to the experienced members. Improper division of labour leads to inefficient teamwork, reducing efficiency. The team responded to this, and encourages the share of experience and techniques between members, such as soldering and how to waterproof parts, to make every member more productive, which mobilises labour and increases their versatility. By improving the division of labour and set up auxiliary tasks for members to handle during their free time, awkward situations where some members have too much work for them to handle, while some members have not much to do could be solved, and no labour will be wasted.

## C. Future Improvements

**Technical Part**

In the current ROV buoyancy system, the magnitude of buoyancy can only be changed manually. However, since the buoyancy level changes according to the environment, incorporation of an automated-buoyancy system to the ROV is expected to be employed instead, which the buoyancy of the ROV can be modified accordingly to maintain its neutrality underwater.

Besides, since our ROV is built to be task-oriented, the ROV may not be suitable for other purposes outside of the task's requirements. Therefore, a multi-tasking model is currently in consideration, which will be made such that it could perform a much larger variety of tasks with little customization.

**Non-technical Part**

As mentioned before, communication is rather lacking in the whole team. We could encourage more communication among team members during the regular meetings, instead of only technical discussion, but also mutual encouragement, which not only motivates each other but also keep members in touch, to facilitate understanding of each other's progress.

## D. Reflection

A considerable amount of members that are new to underwater robotics were introduced into our team this year. By making use of this international competition, we learned more about advanced technical skills required to build and further improve the vehicle. We were also able to acquire knowledge on the possible missions that will be done by NASA on Europa, which led to more understanding on the functionality of different designs. All of these broadened our vision towards the world of underwater robotics.

**Otto So, CEO (Year 4)**:
Being the only old member and the team leader of the project, I am very glad that there are many passionate newcomers this year. It is always good to see there are so much energy and motivation within the team, as they are very active and responsible in their own parts. It is a relatively new experience for me to over-monitor the whole team rather than being a participant in the team. It is very different as I don't have to do any concrete job but to overlook others instead to ensure things are done properly. This has definitely added a whole new experience to my career in this team. I hope that the spirit we now have in the team can be passed to the next generation.

**Max Sze, Team Manager (Year 1)**:
I have always been fascinated by robots, so i was very thrilled to be part of the ROV team, especially when we get the qualifications and see our work paid off. Being a newcomer, I was lucky enough to be the manager of the team. It gave me such a good opportunity not only to reinforce my prior knowledge, but also to explore other field for example programming. This allows me to have a better idea for the whole competition and prepare myself for next year's competition.

**Chan Peter, Chief Computer Engineer (Year 2)**

As a new member of the team, I could feel the passion about ROV throughout the team. It is a memorable experience working with the n In the beginning I thought a ROV was very complicated and hard to build, as time passed we all started to know the importance of teamwork, we all tried our best to finish our given tasks. As a result, we finally finished the whole ROV and qualified to join the international competition. We may face lots of difficulties during the process, but in the end we met our target without giving up.

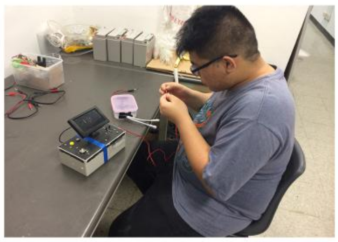

*Figure 27: Team member Chan Peter*

## E. Acknowledgement

From the beginning to the end of the work, our company was lucky enough to receive many help throughout the whole process. CityU Robotic Inc. would like to express their gratitude to the following sponsors:

*MATE Center*
- for organizing the competition, giving us a chance to participate
*The Institution of Engineering and Technology, Hong Kong (IET HK)*
- for organizing the Asia Regional of the Mate International ROV Competition 2016
*City University of Hong Kong and Apps Lab*
- for giving us a huge lab to work on the project
*Office of Education Development and Gateway Education (EDGE), CityU*
- for providing funding and equipment
*Student Development Services, CityU*
- for their providing us funding
Dr. Ray C. C. Cheung
- our supervisors, for his motivation, patience and guidance to our company
Adrian Chan
- our mentor, in which gave us technical and non-technical support along the competition

*Figure 28: Logo of sponsors*

## VI. References

- Mate - The Marine Advanced Technology Education (MATE) Center
  http://www.marinetech.org/

# VII. Appendix

## A. Operational and Safety Checklist

**Cityu Robotic Inc.**

**Operational and Safety Checklist**

Name of Operator: _______________

Operation Date and Time: __________________

*PLEASE complete the list before and after putting the ROV into the water.*

### 1. Start-up Procedures

[ ] Safety goggles are worn for every crew members
[ ] All crew members are not dangerously near to the ROV
[ ] Tether is secure and non-damaged
[ ] All power sources are not on
[ ] All wirings are properly connected, no exposure of wires
[ ] All component's waterproofing status are nominal
[ ] All bolts are secure in position and will not fall off
[ ] The thrusters are not obstructed by any sorts of obstacles, such as wires

### 2. Upon Supplying Power to the ROV

[ ] Ensured that all members are away from the water
[ ] Warned everybody before powering on
[ ] All members are attentive/prepared
[ ] 48 Volt current successfully connected to the ROV
[ ] Warned everybody for thruster test
[ ] Perform thruster test to ensure proper functioning
[ ] Check video feeds, ensure no shoddy images/no feeds
[ ] Test accessories

### 3. Launch

[ ] Hands off from the ROV control panel
[ ] Call "Prepare to launch"
[ ] Deck member ready
[ ] Call "Launch"
[ ] Ensure ROV completely submerged to water
[ ] Wait for release

### 4. In Water

[ ] Check the presence of bubbles due to thrusters
[ ] Check all motors and servomotors functionality
[ ] If burned-out smell is detected, reel ROV back to surface ASAP

### 5. Retriveal

[ ] Call "Prepare for surfacing"
[ ] Ensure crew member ready for retrieval of ROV
[ ] Ensure the ROV is somewhere near for the crew member
[ ] Kill power after confirmation of retrieval
[ ] Ensure no power leak, call out "safe to remove ROV"
[ ] After secure of ROV, call "ROV secured on deck"

### 6. Loss of Communication/ Unresponsive

[ ] Check if all connections are secure
[ ] Reboot the communication system
[ ] If failed: pull out and plug all wires again
[ ] Troubleshoot successful: mission continue as usual
[ ] Troubleshoot failed: Kill power
[ ] Retrieve ROV via tether

## B. Project Budget

| VI. Materials | Total (USD) |
|---|---|
| | |
| ROV Body | $500 |
| Electronics | $1000 |
| Control System | $300 |
| Tool | $500 |
| Flight Case | $300 |
| US Trip | |
| Air Ticket | $20,000 |
| Hostel | $10,000 |
| Transportation | $5000 |
| Registration Fee | $300 |
| Catering | $5000 |
| Entertainment | $500 |
| Other | |
| Registeration Fee | $200 |
| Total | $43600 |

## C. Motor Test Result

Afro ESC Epoxy 1000kv

| pwm | power | current | voltage | weight |
|---|---|---|---|---|
| 1100 | 202.3135 | 16.93 | 11.95 | 1410 |
| 1150 | 177.8681 | 14.81 | 12.01 | 1430 |
| 1200 | 134.9865 | 11.11 | 12.15 | 1220 |
| 1250 | 111.202 | 9.1 | 12.22 | 1110 |
| 1300 | 85.0621 | 6.91 | 12.31 | 1000 |
| 1350 | 56.1384 | 4.52 | 12.42 | 860 |
| 1400 | 29.8928 | 2.38 | 12.56 | 600 |
| 1450 | 8.6768 | 0.68 | 12.76 | 250 |
| 1500 | 0 | 0 | 12.1 | 0 |
| 1550 | 6.7681 | 0.53 | 12.77 | 140 |
| 1600 | 23.199 | 1.85 | 12.54 | 300 |
| 1650 | 51.7497 | 4.17 | 12.41 | 500 |
| 1700 | 80.4995 | 6.55 | 12.29 | 570 |
| 1750 | 113.0593 | 9.29 | 12.17 | 620 |
| 1800 | 143.752 | 11.9 | 12.08 | 710 |
| 1850 | 177.59 | 14.75 | 12.04 | 820 |
| 1900 | 197.5335 | 16.53 | 11.95 | 750 |

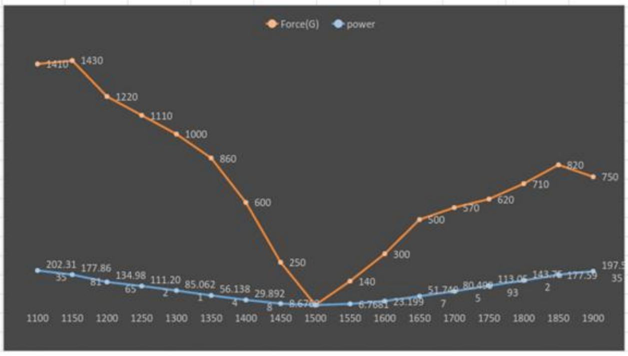


*Figure 29: Motor Test Result - Motor + Esc Underwater*

Afro ESC 1000kv

| pwm | power | current | voltage | weight |
|---|---|---|---|---|
| 1100 | 106.4532 | 8.74 | 12.18 | 670 |
| 1150 | 94.2162 | 7.71 | 12.22 | 660 |
| 1200 | 77.1783 | 6.29 | 12.27 | 600 |
| 1250 | 58.9572 | 4.77 | 12.36 | 560 |
| 1300 | 42.5106 | 3.42 | 12.43 | 450 |
| 1350 | 26.8356 | 2.14 | 12.54 | 370 |
| 1400 | 13.7994 | 1.09 | 12.66 | 240 |
| 1450 | 5.3466 | 0.42 | 12.73 | 110 |
| 1500 | 0 | 0 | 12.91 | 0 |
| 1550 | 3.612 | 0.28 | 12.9 | 60 |
| 1600 | 11.938 | 0.94 | 12.7 | 160 |
| 1650 | 22.662 | 1.8 | 12.59 | 230 |
| 1700 | 38.4076 | 3.08 | 12.47 | 280 |
| 1750 | 53.9835 | 4.35 | 12.41 | 340 |
| 1800 | 71.5792 | 5.81 | 12.32 | 370 |
| 1850 | 87.5875 | 7.15 | 12.25 | 390 |
| 1900 | 104.676 | 8.58 | 12.2 | 430 |

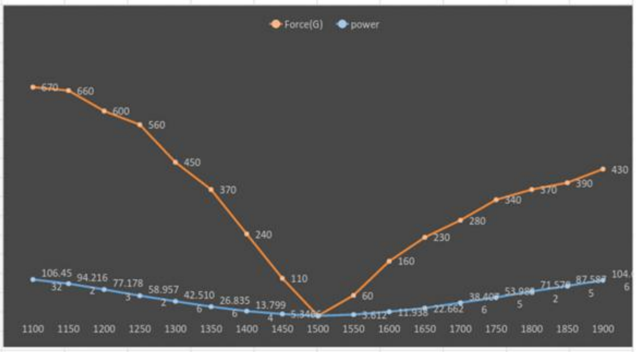


*Figure 30: Motor Test Result - Motor + Esc on ground*