We are the FIRST year !!!

MEMBER LIST

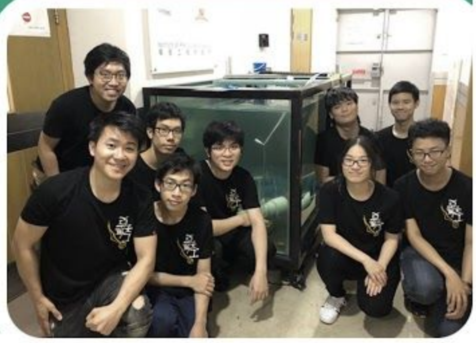
Chief Executive Officer
Cheung Chi Hang Calvin Year 2
Chief Operating Officer
Kwok Pok Man Kendrick Year 3
Chief Financial Officer
Wong Fei Yan Fiat Year 2

Software Engineers
Wong Sin Yi Year 2
Cheung Kam Ho Year 3

Electronic Engineers
Lam Chun Ting Jeff Year 3

Mechanical Engineers
Ho Siu Sum Year 3
Michael Tang Year 3
Kwok Chun Keung Year 3
Fan Chun Yin Year 3
Cheung Tsang Kit Year 3

PowerShuttle Teammembers



POWER SHUTTLE

ROV Name:
Shuttle

Technical Report

香港中文大學
The Chinese University of Hong Kong

Abstract

PowerShuttle consists of twelve students who have experienced in other robotics competition before in mechanical design, electronic and programming development. In order to make a breakthrough, the company developed a Remotely Operated underwater Vehicle (ROV), Shuttle, which is a solution requested by Eastman Chemical Company. The Shuttle can inspect and repair hydroelectric dam, monitor water quality and determine habitat diversity, recover Civil war era cannon and mark location of cannon shell.

Shuttle is the first ROV that the company built. Both mechanical, electronic and software division of the ROV are unfamiliar parts for the company. As we aim to build a ROV that meet the standard Eastman expected, we do lots of study on current ROVs. After knowing the general procedure and various methods for developing a ROV, PowerShuttle put a lot of effort in development cycle, from preliminary work like planning, to debugging and testing. Implementing with modularity and evolvability, members are able to design, construct, and compile the ROV and its control system. The development of the ROV has been improving, letting Shuttle becomes an efficient and effective vehicle with good quality.

This technical documentation describes the development process, detailed design and software system to create Shuttle, the first ROV for our company.

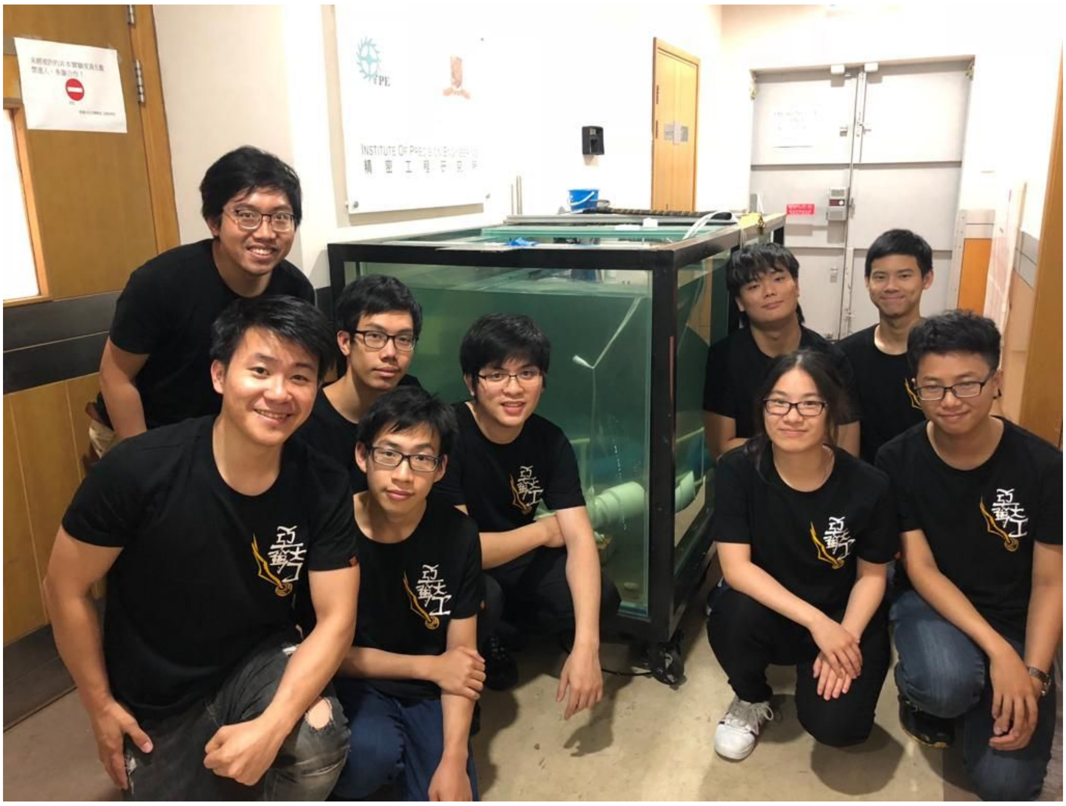


Figure 01: Photo of team members

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Design Rationale

A. Mechanical Design

1. Frame

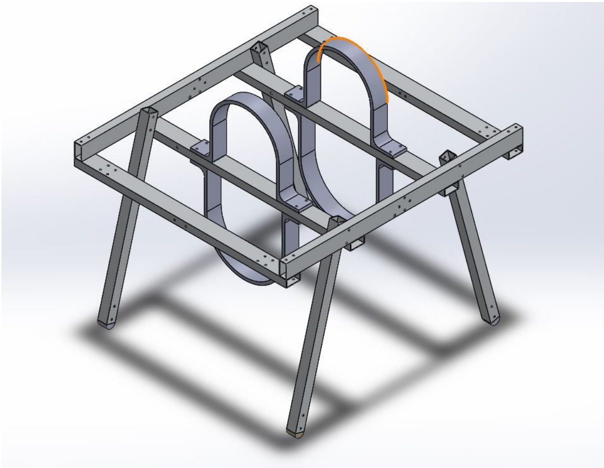


Figure 1: CAD of the ROV frame

Our team members are experienced at using land-use robots with rectangular base. We are inspired by the design and thus attempt to apply to the frame of the ROV.

Aluminium alloy is selected as the material of the frame. It is light, durable and rigid compare to PVC pipe, acrylic plastic and foam.

We first locate the fundamental elements of the ROV in the frame. Two electronic enclosures at the centre and thrusters at the surrounding. Simply adding U-shape mountings to hold the enclosures is the solution. During varies testing, we always had a hard time to put down the ROV onshore as there are task-oriented devices at the bottom of the ROV. For having a more convenient way to place the ROV on land, four legs are added with ball shape 3D-printed parts at the bottom. This can prevent damage deal to the devices or ROV and slightly stabilize the ROV when it is at the bottom of the pool.

The frame can be divided into three layers. The top layer has an enclosure, the middle layer has enclosure and thrusters, and the bottom layer has only the four legs mentioned. Different task-oriented devices are assigned mostly at the bottom layer to achieve better performance with easier control for the driver. Some devices will occupy space of the top two layers as they need to place in vertical direction and themselves are relatively large in height.

2. Propulsion

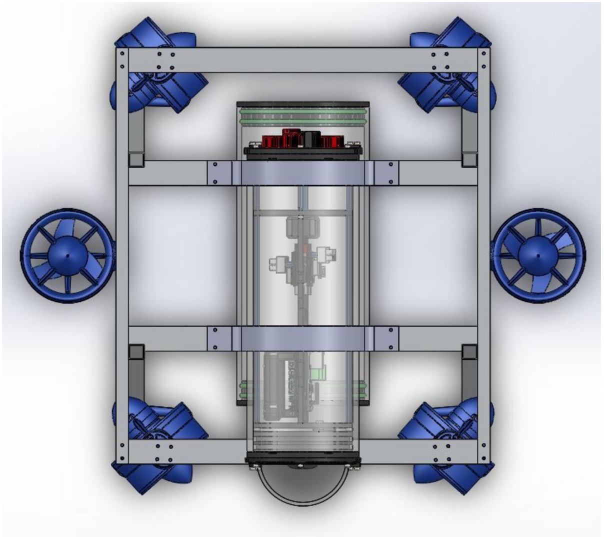


Figure 2: Top view of ROV (thrusters indicated in blue)

The movement of the ROV is driven by six thrusters. Two facing at vertical direction and four facing at horizontal direction. The thrusters are located and rotated to provide up to four degree of freedom(DOF) of the ROV movement.

The two vertically placed thrusters generate force in vertical direction, providing one DOF. Therefore, the ROV can achieve up and down motion(floating and sinking). Both thrusters are located farthest from the centre of the ROV to provide larger moment for stabilizing the ROV.

The orientation of the four horizontal thrusters are designed to a rectangle-like formation. Each of the four horizontal thrusters is rotated for around 45 degree to achieve three more DOF: front-back, left-right, and rotation. As a result, the ROV can move freely in the water and do the assigned tasks.

3. Electronics enclosure and sealing

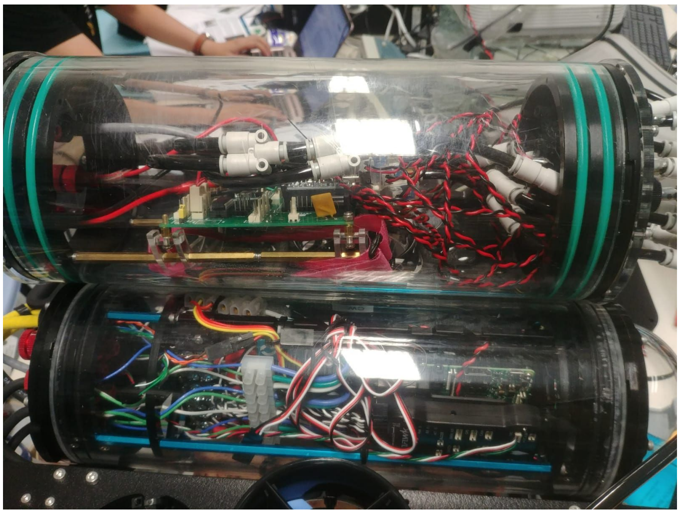


Figure 3: Electronic enclosures

Shuttle contains two electronics enclosure. One is used to encloses the electronic parts of the locomotion control system, including printed circuit boards(PCBs), wiring and a camera. While another encloses the electronic parts of the manipulator pneumatic control and sensor reading system, including PCBs, wiring, solenoids and pneumatic tubes.

The enclosures consist of three parts, cylinder, cap and cover. Acrylic cylinder with 5mm thickness is selected as the chamber to store the electronic parts. At each ends of the cylinder, a cap implemented with o-rings is used for sealing. The cap is designed to hold three o-rings, two at the side and one at front facing out of the enclosure, the cover can be mounted with screws at the front side of the cap. O-rings can prevent water leakage from gaps between the cap and the chamber, and between the cap and the cover.

Electronic parts inside the enclosure are mounted on an internal structure which is constructed by laser-cut acrylic plates and metallic support beams, while the structure is fixed at the cap. This method can seals the enclosure and provides an easy way to access parts inside the enclosure. Users can simply pull out the cap which is mounted with the cover, then perform maintenance tasks for the electronic parts.

Firgure 4: Hollow screw with wire fixed by epoxy

In our design, electric wiring and pneumatic tubes need to extend out of the enclosures for sending signals and providing pressurized air for pneumatic control respectively. Laser-cut acrylic/aluminium plates with holes are used as the cover. Hollow screws and nuts with o-rings will be fixed at the holes which allow wiring and tubes to exit the chamber. Epoxy is poured into the screws for sealing the hollow space. The sealing of the enclosure is achieved by using o-rings and epoxy. Silicon grease is applied on the o-rings to prevent wearing.

B. Electrical & Electronic Design

1. Power Distribution

The electrical & electronic system are responsible for providing power, controlling and communication between on-shore device and ROV device. 48V to 12V adaptor is used to supply voltage for thrusters, camera, solenoid, and mini ROV.

2. Control System

The ROV control system can be divided into two separated part due to the principle of separation of concern. One is responsible for ROV locomotion control and main GUI; the other one is responsible for manipulator pneumatic control and sensor reading.

The locomotion control system using QGroundControl(QGC) on topside computer, a open-sourced software, as a user interface for ROV operation. The QGC take input from xbox controller and transmit it to Raspberry Pi3 through ethernet. The Raspberry Pi3 runs a software served as a relay between QGC and pixhawk. Once the pixhawk received signal, it would control mostly 6 thruster by sending pwm signal to Electronic Speed Controllers (ECS). The control system allows smooth and stable movement in 4 DOF. Also, it provide heading and depth holding features.

There are two arduino nano board responsible for the other part. One is for pneumatic control, and the other one is for sensor reading and data processing.
For the pneumatic control board, it connect to a VEX controller onshore. The controller able to toggle different pneumatic by pressing different button. For safety reason, the button will be disabled unless a button for safety unlock is pressed. The board connect to all pneumatic control installed on ROV.

For sensor reading, the board will connect to a LCD display placed onshore. The value handled in the board is displayed instantly after handling. All sensors installed on ROV connect to the board, and send the analog signal.

3. Tether

The tether consists of 6 main cables: 2 power line, 2 pneumatic pipes, 1 signal cable which consist of 4 twisted pair cables, 1 AV signal cable.
One twisted pair cable is used for communication between topside computer and Raspberry Pi3, while other twisted cables are used by Arduino control system for sensor reading and manipulator control. The two pneumatic tubes are used for supplying and exhausting pressurized air which used by pneumatic actuators. The two power line are 48V and GND.

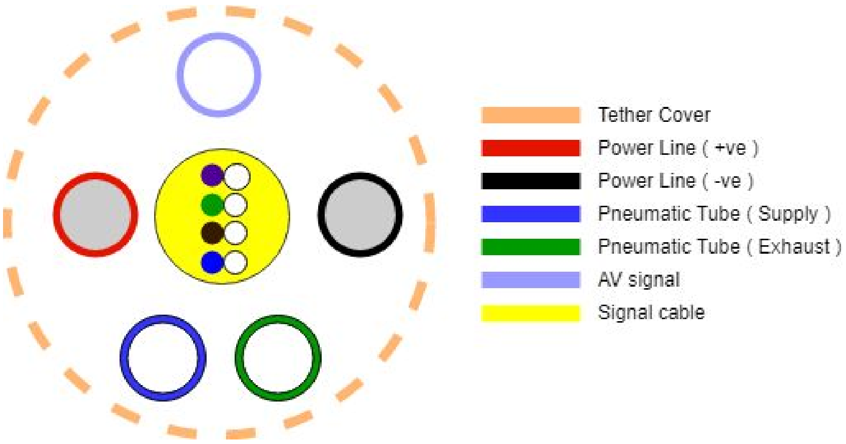


Figure 5: Cross-section diagram of tether

C. Software Design

1. Computer Vision

<u>a) Autonomus Image Recognition of the benthic species</u>

We utilize the main camera of Shuttle for benthic species recognition by streaming the video input from the camera to the on-shore computer. Then we deploy the shape detection software to capture the details of the benthic species under the rock and finally display the result on the output window. The implementation of the software mainly relies on the open-source library OpenCV.

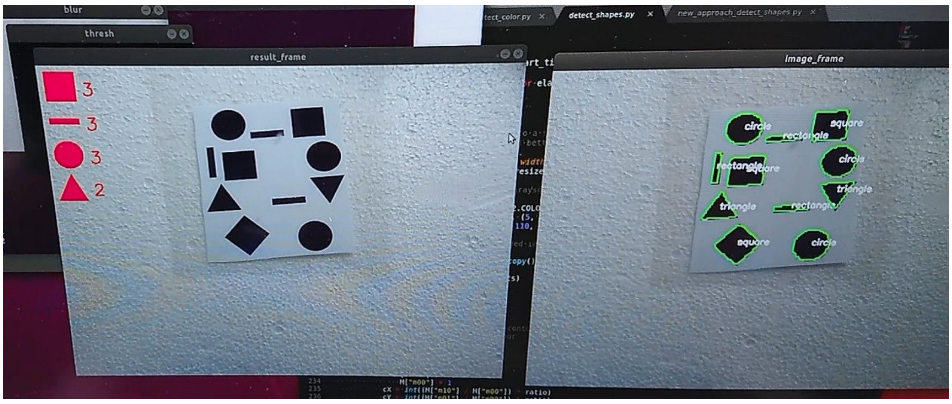
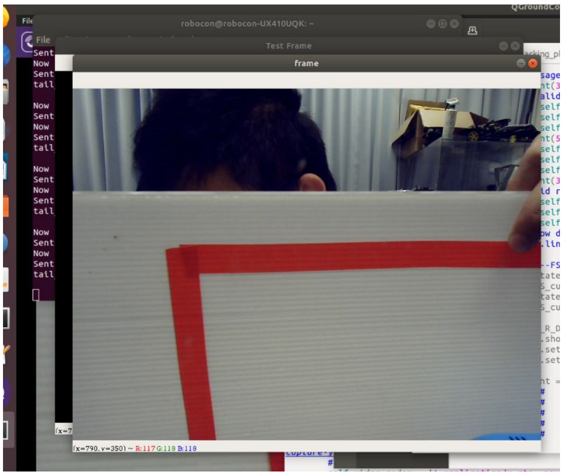


Figure 6: Testing of the shape detection software

b) Line Tracking

This whole task is that the ROV follow the red line and measure the length of the blue crack and finger out the location of the crack. We implement the automatic line tracking program by using OpenCV. The program detects the 4 sides of the screen whether the red line occupies them. By the result the camera captures, we apply the FSM model to the program to recognize the tracking direction and change of tracking direction.



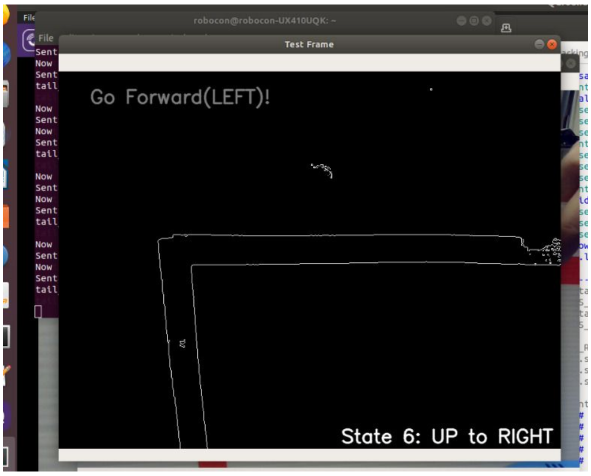


Figure 7: Original frame captured

Figure 8: Frame after processing and analyzing the original one

c) Line Measuring

We need to measure the length of the blue crack by the frame that we captured. The way to measure the length is that we find out the ratio of the length and the width. For accuracy and stability, we take the average length of 100 samples as a result. We assume its width is 18 mm and the perspective of view is perpendicular to the crack.

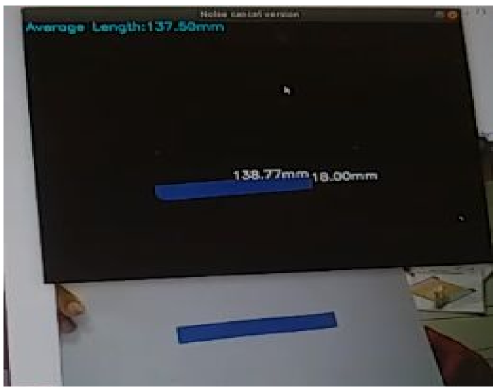


Figure 9: measure blue crack in frame captured

d) Crack Position Marking

We need to mark the blue crack in a correct region of the red line tracking area that divided by 12 blocks. By the time ratio of taking the whole path and approach the blue crack, we can get the result we want.

D. Mission specified tools and payloads

1. Pneumatic Multi Purpose gripper

The vehicle is equipped with two vertical lifting grippers. The grippers are oriented to accomplish several tasks, such as replacing the damaged screen of the trash rack, lifting the rock from bottom, removing the regraded rubber tire, installing a new reef ball and returning the cannon to the surface of the side of the pool. The small gripper are designed to fit the cannon tightly in order to grab the cannon nicely and firmly in order to secure the cannon when holding it. Also the small gripper appears to be a ring shape when it is closed. It is designed for holding the 20mm tubes objects such as the screen and reef ball. The bigger gripper is designed for grabbing object with larger radius, such as the tire and the cannon. It does not fit its target tightly so as to allow the object could rotate freely. This mechanism could prevent from twisting when the centre of gravity of objects do not align with vertical gripper.

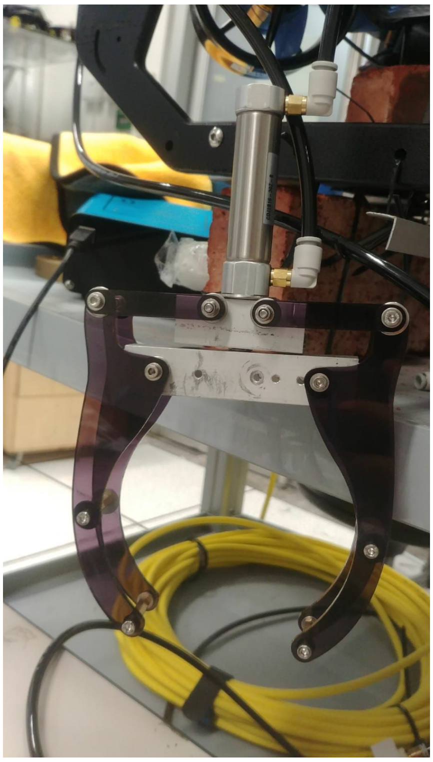


Figure 10: Large gripper

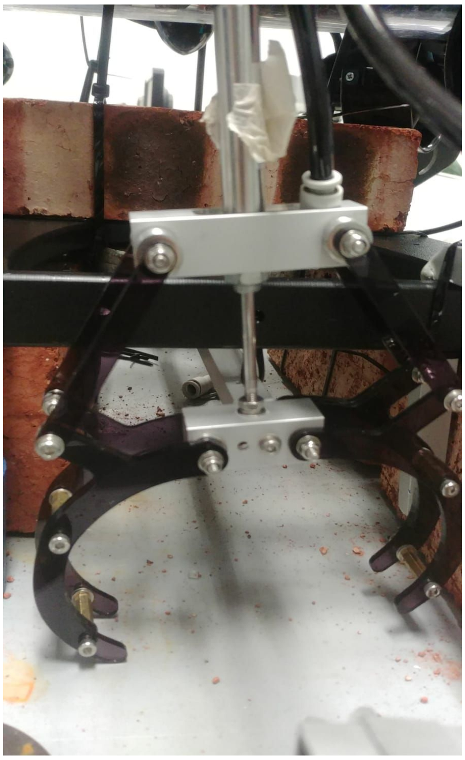


Figure 11: Small gripper

2. **Dropping System**

We use a plastic container that can hold grout and trout fry, and a pneumatic cap opener placed at the end of the container. Also, there will be a guiding from the opener to the container under water. Once the ROV arrived to the destination, and the guiding is in well position, the opener will be triggered by the controller. The grout and trout fry will fall and hold well in the container under water.

Figure 12: Pneumatic lid opener

3. **Sensors**

The vehicle included an extra Arduino Nano, which retrieve the data from various kind of sensors. First, it will be a metal detector, that helps to detect metal. A 3D printed guiding will guide the sensors toward to the target. Second, a temperature sensor (LM35) that send the temperature analog signal to Arduino board, and the board will handle the data and analysis. Third, a PH meter (E-201-C) that can detect hydrogen ion concentration in the solution will be placed. An actuator will be placed near the meter, which helps the meter for getting the data. he Arduino Nano will process the data, and finally there will be a 16x2 LCD displays for showing the processed result.

Figure 13: metal detector(left), PH meter(middle), Temperature sensor(right)

4. Measurement Tools

Our mechanical engineers designed a ordinary measurement tool, as shown in Figure below. We use it for measuring the outer and inner diameter of the cannon. It is inspired by vernier caliper. With a pneumatic actuator, it allowed us to slide one of the outside or inside jaws. After sliding, we read the scale of it.

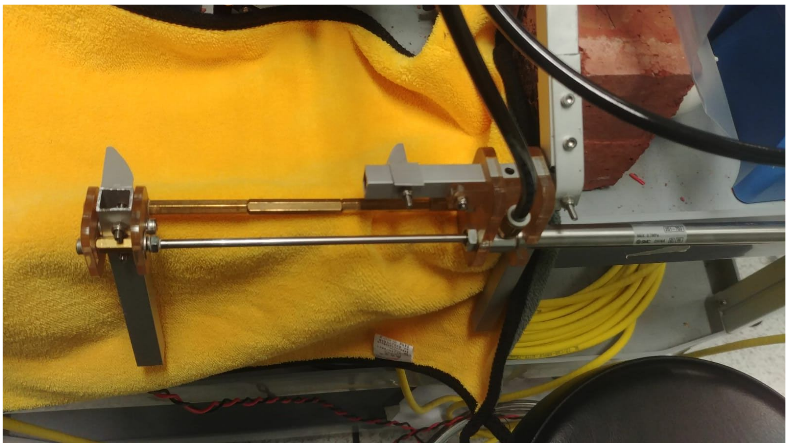


Figure 14: Caliper

Also, we read the marking of the measuring tape through a camera after we put the metal strip at one end of the cannon and extend the tape.

Figure 15: Measuring tape

5. Mini ROV

Material:

position	Material	Quantity
A	30mm Epoxy propeller	1 pair
B	O Ring (D55, D45)	2
C	Acrylic diameter 60mm tube	55mm
D	Bearing tubing and shaft	2 pairs
E	GEE130 motor	2
F	Camera with LED	1

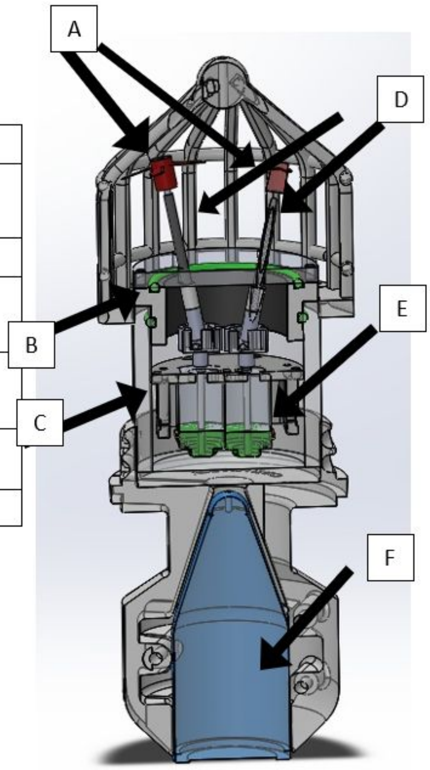


Figure 16: Parts and position of mini ROV

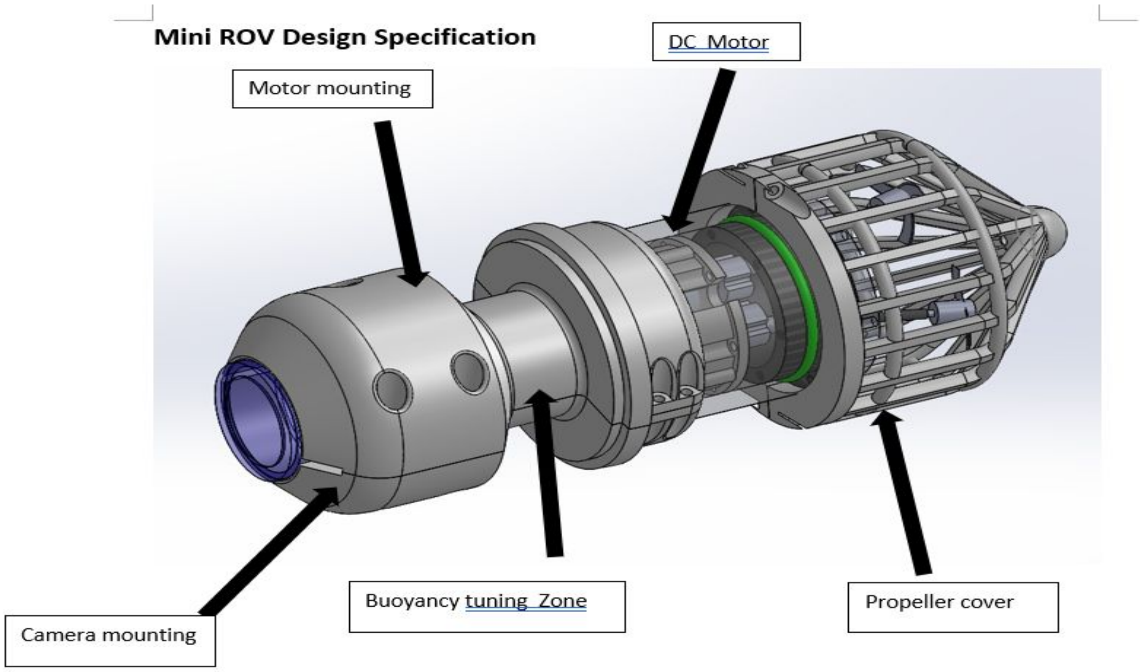


Figure 17: Design specification

Functions

Camera mounting	-To ensure the camera is hold firmly to the mini ROV body -Smoothen the head of the Mini ROV to prevent crashing
Buoyancy tuning Zone	-Adjust the buoyancy level by allowing adding load or flowing materials
Motor mounting	-Aline the two motors at specific position -Spacing the tube to allievate the virbration of the motors
Propeller Cover	-Achieve IP20 **International Protection Marking, IEC 60529 standard** -Enable the Mini ROV moving backward without crashing
thin plastic flims revolved:	surface smoothening by revolveing aroud the mini ROV body

Table 1: Functions of parts of mini ROV

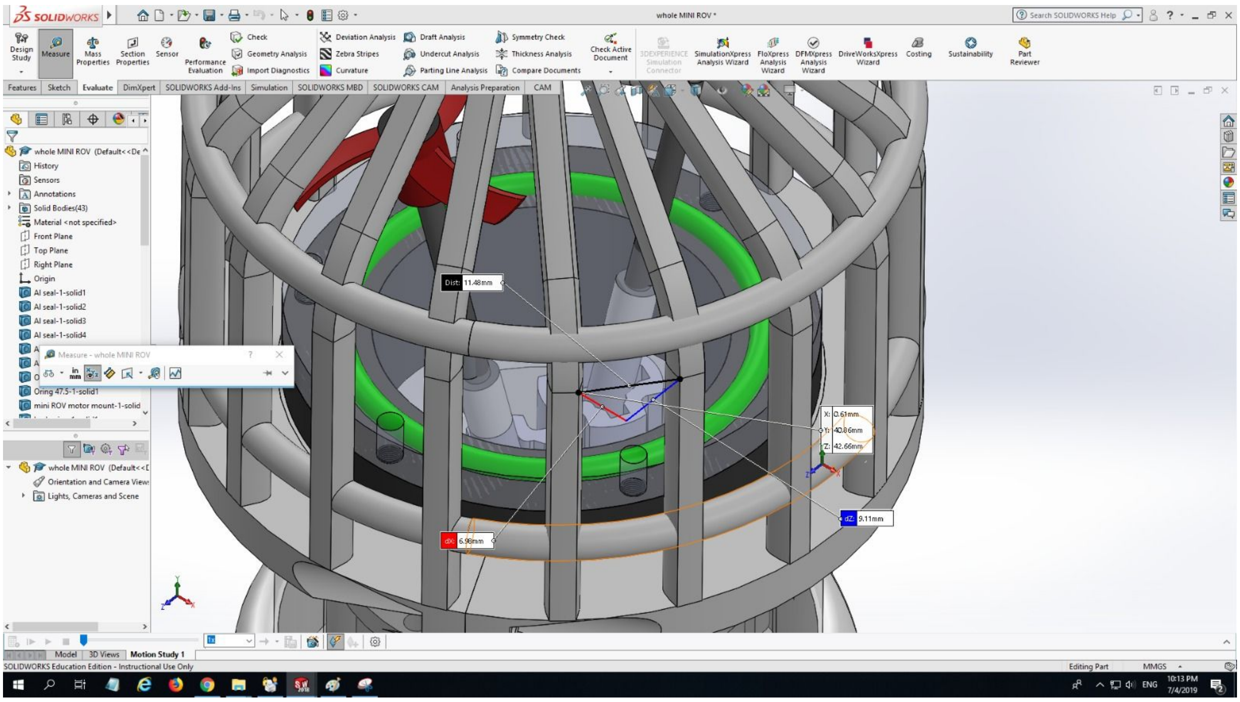


Figure 18: IP 20 standard checking

Electronics Specification:

Camera

Figure 19: Camera in mini ROV

Operation voltage	6-12V
Operation current	5A
Image	colour
Visible distance	1-3m
Wide angle	145 degree
Frame Rate	60

Table 2: Camera specification

Figure 20: DC motor

Operation voltage	6-12V
No load current	0.75A
Full load current	2.59A

Store current	2.89A

Table 3: DC motor specification

Challenges:

The Mini ROV is required to run smoothly inside a rough tube in both forward and backward directions. The pipe is not only rough, but even folded like organ. Any solid featured with corners and convex structures might easily encounter critical crashing on the wall of the organ like inner wall of the pipe. The whole mini ROV would be stopped and turn it to a wrong alinement angle more than 45° from the correct direction. Time will be wasted on realignment. Thus, both the head and the tail of the mini ROV is fileted and slanted . As figure 1 suggested, the camera mounting front is fileted. All the screws are hidden under the shells so a to prevent crashing.

Waterproofing Process

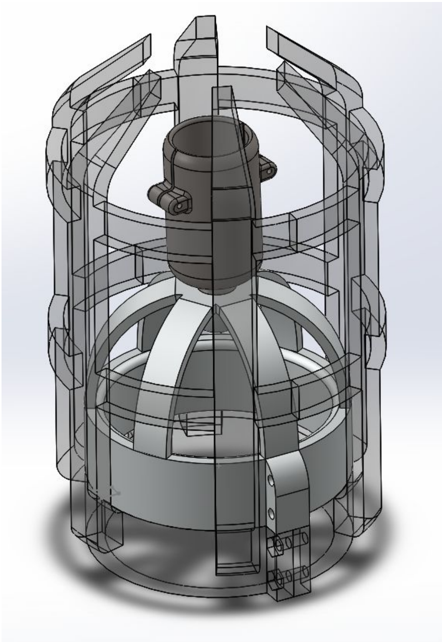
The task requirement is simply driving a small ROV inside a underwater pipe ,and returning when a sign is seen. However, devil is in the detail. We found that it is one of the most challenging task. Let us looking into the difficulties steps by steps.

The mini ROV is just a small version of the main ROV, which is also challenged by the underwater environment. The most strenuous part of building the mini ROV must be the water proofing process. Sealing holes and walls on a ROV is not difficult, simply by applying AB glue can keep water away. However, mini ROV is a self driven device that have to face the high pressure water ahead when it is moving. Sealing is only a measure for a steady system but does not work for the moving parts. After a series of testing, we found that the the rotating shaft is the major source of water in. Despite applying large excess grease between the bearing tubing and shaft, high pressure water spills into the mini ROV. We applied inverse flow testing and test the water proofing ability of different types of grease. Grease of higher viscosity is preferred as it stays in the bearing tubing more firmly when the shaft is rotating in a high speed. Warming the grease would ensure the even and smooth spreading of the viscous oil though the tube. Thus, the shaft stays hydrophobic all the time.

Choice of materials for camera and motor

Working in dark pipe under water, lighting system and camera quality are both important factors to consider. We decided to use visible white light instead of infrared, so as to distinguish the sign from the pipe concave depression, while infrared lighting system only returns monotone visual signals.

We had more than two candidate of camera. The major difference are the size and weight of the camera body , the size of the aperture and the range of sight. Small camera are more handy and flexible. Mini Rov carrying a small camera can move more freely in a pipe, nevertheless, the balance of weight and centre of gravity would be easier. However, we gave up the benefit of a small camera but chose a bigger camera. It is because the aperture and range of sight is larger, moreover , the visual signal would be more stable with less chance of critical collision on the pipe wall as a more massive system have a higher inertia. The larger range of sight can always ensure notifying the sign while the sight of a small camera is sometimes blocked and it is more difficult to aline with the sight to proper position.



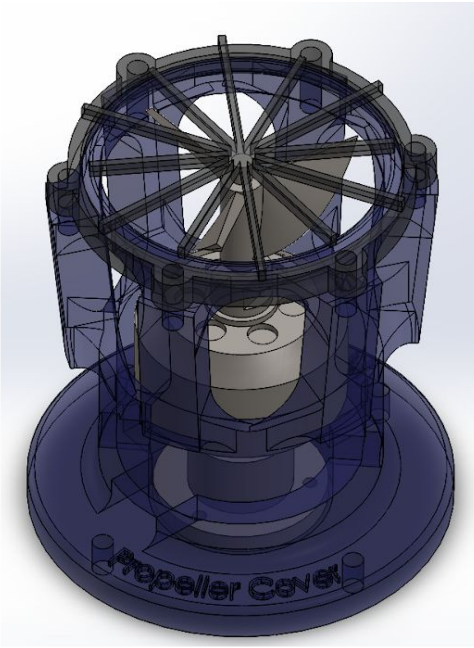


Figure 21: Small camera set

Firgure 22: high power motor set

Safety

A. Safety Philosophy

Safety is the top priority concern of PowerShuttle. In the company, you can damage a diamond, but never the human. Hence, PowerShuttle provides enough personal protective equipments and safety workspace for every team member. An established workplace safety protocol was designed and implemented in all working procedure.

B. Safety Features

1. Mechanical Safety Features:

Figure 23: Thruster with safety cover

All thruster are shroud according to the IP-20 standard.

Figure 24: A member using heavy machinery

Heavy machinery is used for drilling into the aluminium parts. Each members is required to wear safety equipment when using the heavy machinery.

2. **Pneumatic Safety Features:**
   An air pump is used for supplying pressurized air. The pump has a high pressure release valve which will automatically release air when the pressure inside the pump is higher than 8 bar.

3. **Electrical Safety Features:**
   Each circuits is connected with a fuse for safety concern. On-shore emergency button is implemented into the control box for quickly power cut-off by the pilot.

C. Lab Safety Protocol

Specific safety protocols are implemented for using the lab. Every members are well-trained, being able to use every devices inside the lab. Every access are recorded to trace the usage of the lab. Safety equipment is required for using any device.

Logistics

A. Company Organization and Teamwork

PowerShuttle have three major team: Management Team, Mechanical Team, and Software and Electronic Team. Although separated into three team, members are doing the three roles simultaneously. Management Team will build a communication bridge between different teams, so as to enhance the communication. The team will also ensure the works done by different team are compatible with each others. Mechanical Team do the mechanical design, build and assemble the mechanical parts for ROV. Software and Electronic Team weld the cable, and connect different mechanical parts to the control board. The team ensure all mechanical part can control well under a safety situation. Besides, software team will develop computer vision in order to enhance the output accuracy, and convenience the controller control.

Before PowerShuttle start work, all teams will gather for a meeting. Planning of hardware development and outlining timeline are discussed. All team prepare for the items discussed after the first meeting. During work, a demo is conducted weekly so all team can gather for information sharing. Management team will also monitor does the team followed the timeline strictly, or otherwise, personnel change are made so as to keep track for the schedule. Mechanical Team, Software and Electronic Team will implement testing regularly to ensure the correctness, reliability, robustness, and security of the design.

Challenges

A. Technical Challenges

a. Water-tight enclosure

Making watertight enclosure is the fundamental and key technique for building a ROV. As no one has any experience on making water-tight, we did lots of experiment techniques and materials like O-ring, epoxy, etc to make the enclosure watertight, and continued for months.

During those experiment, disaster did happen. Water flooded into the enclosure. Luckly, we were using an empty enclosure to test it.

b. Image recognition

When we are working on the image processing tasks, we have faced several challenges. When we tried to identify the pattern of the benthic species using the camera, we tried to recognize different shapes using simple contour detection. Unfortunately there are many noise detected from the image and it hugely affected the performance of the program. Furthermore, after several testings we have discovered that different lighting can cause lots of troubles. To reduce the effects of those external to our program, we need to apply extra filters to our working image in order to output an acceptable result.

c. **Pneumatic design**

Although we are experienced at designing pneumatic devices, we still underrated the weight of the grout and cannon in the water. With limited pressure, we had encountered issues where the lid opener and grippers cannot hold the pebbles and cannon. We change the design and use TOGGLE mechanism to reduce the force given by pneumatic actuator. After changing the design of grippers, both devices are now operating with stable and reliable performance.

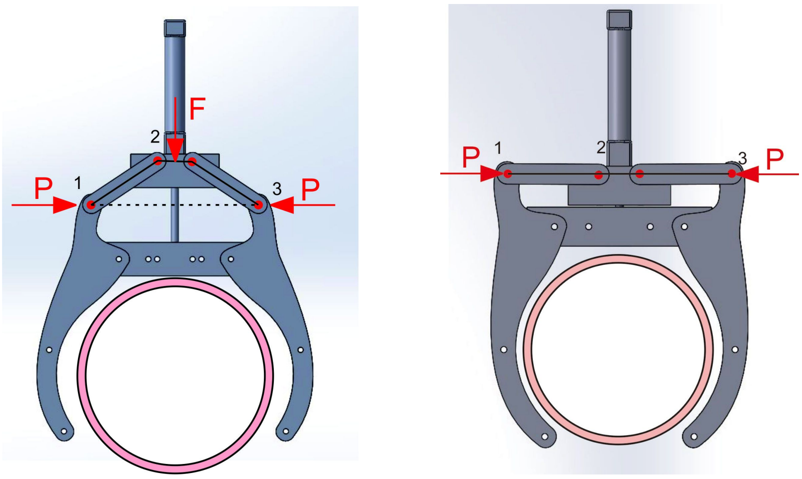


Figure 25: Force Diiagram of Toggle Gripper Mechanism

B. Non-Technical Challenges

a. **Condense working hours**

Since we are not familiar with operating nor developing a ROV, we need time to get ourselves familiar with all those knowledge. Once we think we can enter creating phase, the contest is just months away. To catch up with the schedule, most of our members have to sacrifice their personal life to develop the ROV. Sometimes we worked so hard that we forgot to have any meal. Therefore, we establish a dayoff scheme in order to maintain a work-life balance for our members.

Lessons Learned

A. Technical

Since this is the first year we develop a ROV, we need to familiar ourselves with knowledges from many different aspects. From waterproofing to framework design, from image processing system to various sensors integration, we have to explore many new grounds in order to create a fully operational ROV.

Waterproof techniques is fundamental for constructing a ROV. Without a proper sealing, the ROV can never go underwater. Our members learn a lot of sealing mechanisms and methods through experiments, their skills of sealing has improved as well.

When we are working underwater using the ROV, it is inevitable that we need to rely on cameras to help us gather informations underwater. The lightings that we may experience underwater can be very different from the lighting on ground. Other than solely rely on the main camera, we need several supporting camera to help us capture different view underwater to help us finish the tasks and protect our vehicle. We learned the importance of building a robust software system to deal with unexpectancy.

B. Non-Technical

Communication and management are extremely important among a group of people. During the preparation for the competition, members have different ideas and arguments. We were having communication and management problems which result in confusion and delay of progress. As time goes on, members are more experienced with their roles and communicate in more effective ways. Arguments and misunderstanding still occur but members are focusing on finding solutions.

Future Improvement

Due to our inexperience in developing ROV and the lack of time, we cannot spare the resources to develop our own control system. Throughout the year, we studied about the control system that we purchased. We have learned about how to control different thrusters with synchronization. With this year’s experience, we can try to develop our own control system in the future to gain a better control over the ROV. If we can develop a new control system, we will also implement a new graphical user interface for the control system.

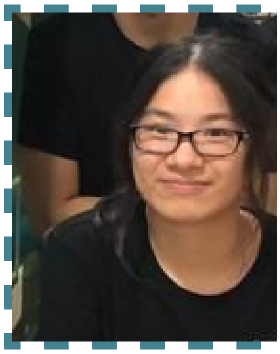
Reflections

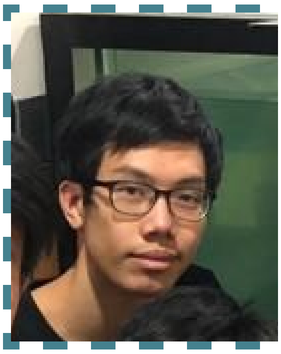
Kwok Pok Man Kendrick (Chief Operational Officer)

“Building a team from scratch, it can never be an easy task. When I first joined PowerShuttle, none of us has any experience about remote operated vehicle. Due to our inexperience, we have met many challenges throughout our development process. There are so many times that I want to give up. I am blessed to have a great team backing me up. Joining PowerShuttle does not just give me an opportunity to test my knowledges, the most precious lesson that I have learned is how to work with others and how to manage a team.”

Wong Sin Yi (Software Engineer)

“There are lots of sensors used which we have no experience in using them. It is difficult for us to understand how the temperature or Ph value being retrieved and analysed. We lack experience on electronic stuff, so we put a lot of effort on doing research and testing. It has been a tough job, but it is rewarding when we are able to manage it. Thanks for the support from other teammate, and anyone who helps powershuttle, it is a great honour to participate in this competition, and help us grow a lot. ”





Cheung Chi Hang Calvin (Chief Executive Officer)

“ We lack experience on doing underwater mechanics and programming. It is a huge challenge for us to start working. Although I have diving experience, the characteristic of robot underwater is not that easy. Most of the challenges are unexpected, and difficult to solve. However, we still try our best to figure out the problem and solve it. Thanks for anyone helping PowerShuttle. If there were no support from the experienced, it is nearly impossible for us to participate in the competition. This experience help me to realized the importance of team spirit, and we can achieve the things once Power Shuttle are gathered”

Corporate Responsibility

Community Outreach:

PowerShuttle understands the importance of nurturing young engineering talents in the society. We seek every opportunity to serve our community to promote engineering. When we noticed that HKUST is holding Underwater Robot Competition 2019 to promote iSTEM education in Hong Kong, we participated in the event as the event helper. The competition provides several workshops to the participants of the competition. From those workshops, the participants have learned several essential idea about underwater robots such as buoyancy testing and mechanical design of the robot. Our volunteers also benefit a lot from this competition. With this experience, we hope we can host similar events to raise the public awareness towards engineering in the future.

Our member worked as a volunteer in aiding the video shooting of the participant.

Acknowledgement

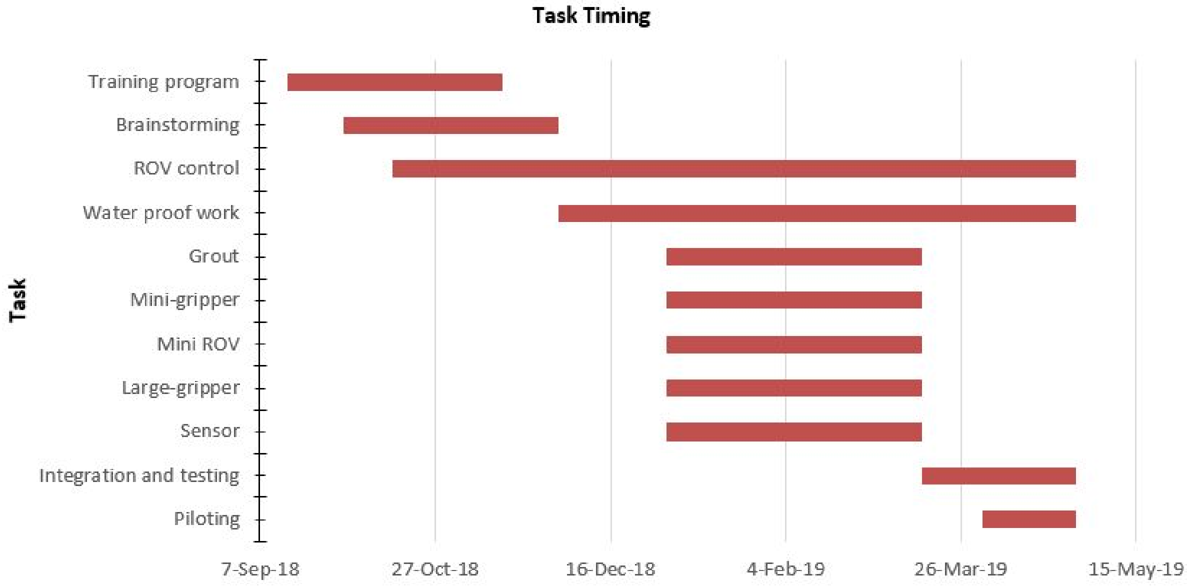
Power Shuttle would like to express our sincere appreciation to our supporters:
The Faculty of Engineering, CUHK - for their generous support, sponsorship
The Department of Mechanical and Automation Engineering, CUHK - for their technical support and providing labs to use
CUHK T Stone Robotics Institute - for their technical support

香港中文大學
The Chinese University of Hong Kong

香港中文大學
天石機器人研究所
CUHK T Stone Robotics Institute

Appendices

Gnatt Chart:



Budget Report:

Category	Item Description	Price (HKD)
Material	Pneumatic actuator	HK$600.00
Material	Epoxy	HK$450.00
Material	Carbon fiber sheet	HK$1,000.00
Material	Aluminium	HK$200.00
Material	PLA	HK$560.00
Material	Enclousre	HK$600.00
Material	Material miscellaneous	HK$860.00
Materials Sub-Total (1)		HK$4,270.00
Electrical component	Anderson SBS50	HK$90.16
Electrical component	LittleFuse	HK$13.67
Electrical component	T200 Thrusters (6 pics)	HK$10,140.00
Electrical component	30A Electronic Speed Controllers Thrusters (6 pics)	HK$1,500.00
Electrical component	Xbox Controller	HK$50.00
Electrical component	Rasberry Pi 3	HK$285.00
Electrical component	Pixhawk	HK$1,200.00
Electrical component	DVR+Cameras	HK$480.00
Electrical component	Solenoid	HK$1,200.00
Electrical component	Electrical component miscellaneous	HK$520.00
Electoric components Sub-Total (2)		HK$15,478.83
Shuttle Cost [(1)+(2)]		HK$19,748.83