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參展科別　工程學

作品名稱　Designing Multifunctional Intelligent Autonomous Underwater Remote Operating Vehicle to perform “Search and Rescue” in the event of extreme weather flooding condition

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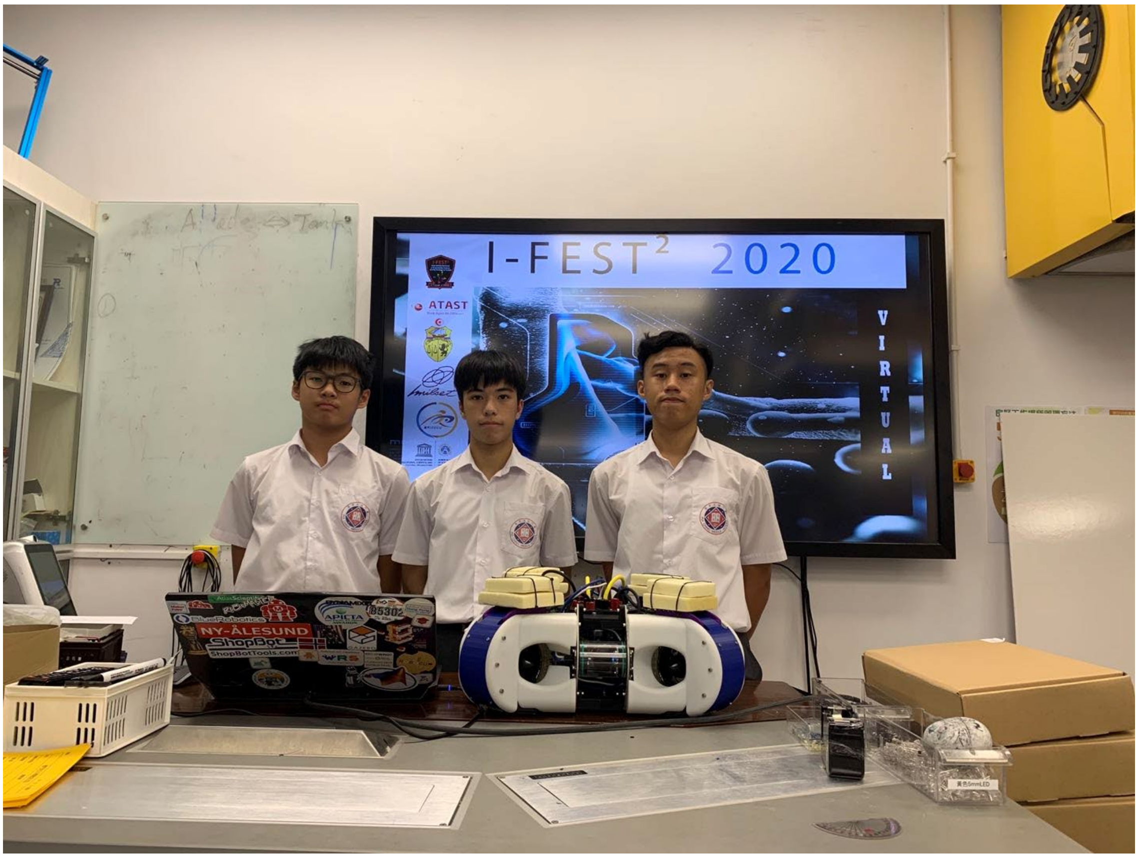


Abstract

This underwater remote operating vehicle (ROV) is designed with and without tethered operation. The operator can control the ROV from the real time first-person view in graphical user interface combined with sonar and object detection function when the tether is attached to perform search and rescue. The control tether with fiber optic lighting cable establishes a guided link medium between the possible search victim location and the rescue team. When the tether is detached, rapid deployment by a predefined set of instruction to achieve further operation range. The intelligent technologies of signal processing were used for object recognition, collision detection and sonar scanning data to enhance underwater operation. Autonomous driving is based on software development with limited capability to run in unrestricted open areas. We have achieved the design intent and confirmed the performance data in the laboratory boundary conditions.

Introduction

The project called Multifunctional Intelligent Autonomous Underwater Vehicle started in June 2017 and continues until now. This project was funded by the ROV team in FABLAB at Macau Pui Ching Middle School since the idea has appeared.

The project has been a three-year-period fully-independent-development. Our team aims to achieve "search and research" in the event of extreme weather flooding conditions. Searching for missing persons who may be harmed or confirmed to have been harmed or even threatened with death in certain environments or places, followed by rescue operations.

fig.1 Fully-independent-development vehicle

The impacts of climate change are manifold, and the number of floods, in particular, has increased drastically. The frequent occurrence of floods does not only affect the lives of a considerable number of people living in low-lying areas but also take away more than 10,000 lives annually.

Two years ago, Typhoon Hato seriously lashed Macau and caused a huge torrential rain. Together with the astronomical tide, Macau's coastal area experienced a serious flood. Unfortunately, 5 of 12 people died from being trapped underwater in underground car parks. In the same year, the US was also struck by a Category 4 hurricane, Harvey, which resulted in 70 deaths, with 80% of whom died of drowning. The high fatality rate of tropical cyclones mainly derives from the difficult Search And Rescue (SAR) operation. If a normal healthy person is trapped and drowned during a flood, he/she can only hold their breath for approximately 2 minutes, which is barely sufficient for the rescue-diver to search, identify and arrive. In the interim, the rescue operation is often conducted in a low visibility environment with various uncertainties like sharp objects, ropes tangling around, and cars floating.

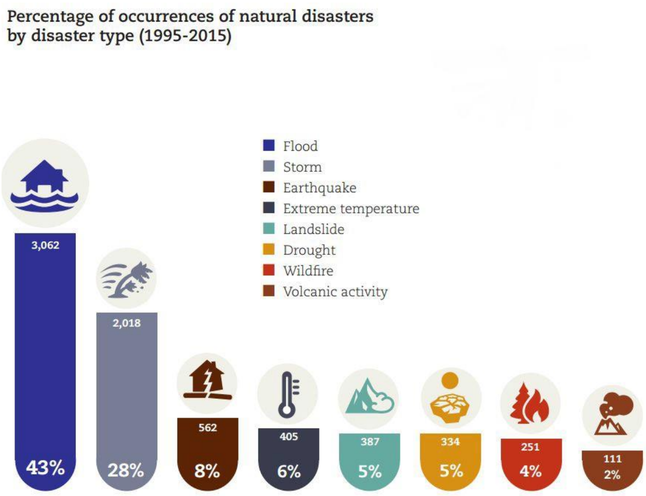


fig.2 Percentage of occurrences of various type of natural disasters

The main target to innovate our operation system is "user friendly" to face extreme weather flooding conditions in a short period. Including a stable maneuvering algorithm, sonar data representation, object detection, and a quick-release system for interchangeable cassette type of tools set. These functions can improve our aim in the operation system.

Within the there-year-period, we have worked out various experiments for physical analysis in our lab. For example, flow simulation of our thrusters, light lux experiments, velocity, buoyancy, and movement stability test. These tests can provide adequate preparation before an on-side performance.

The team started to test in an authentic environment since last year at the lakeside in Macau, such as *Picnic Park Dam Of Ká-Hó* and *Praca do Lago Sai Van*. The team can achieve a stable operation of the ROV. However, this authentic environment does not fully equal to the real flooding conditions. Therefore, we aim to test in a simulated flooding environment with various assistance, such as a wind maker, etc. This is also our future target.

Operation

Before extreme flooding condition commerce, our ROV would be ready in the nearby area which might have a chance to encounter a flooding condition, such as a low-lying area.

After the flooding condition is confirmed, the ROV would be operated by the operator to the low-lying area with tethered mode. In this mode, the operator can control the ROV in the first-person view through the camera deployed in the ROV. Considering the flooding condition is happened to be a low visibility area, two LED lights (1,500 lumens, 135 degrees) were deployed in the ROV achieving to catch sight of a range of 1 meter. Moreover, sonar and object detection are also representing to be assistance in the searching process. With this assistance, our operator can control the ROV to the target destination.

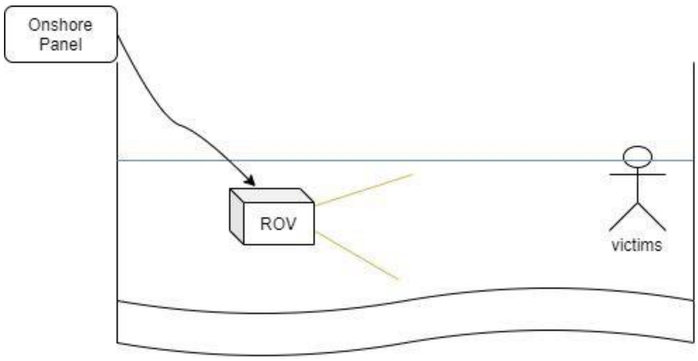
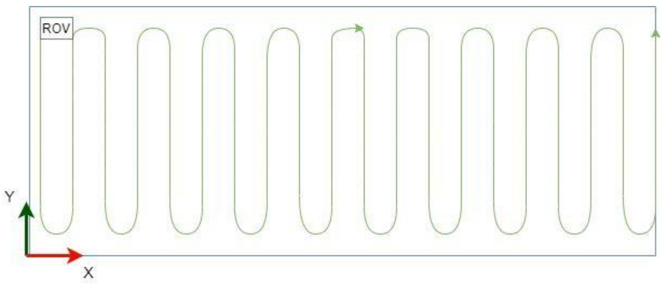


fig.3 Tethered ROV searching for victims in the flooding condition with LED lights deployed

When confirmed a victim in the flooding area, the rescue team would distinguish the rescue process from two options based on the real-time situation. The first option is when the victim is in a conscious situation, which means the victim can notice the ROV and is drowning condition. In this option, the rescue team gets to the victim's destination with the fiber optic lighting cable which is established to be a guided link medium between the search location and the rescue team. With this guided link, the rescue team can reach the victim's destination in the shortest time. Another option is that when the victim is confirmed to be trapped or got stuck with some certain objects, which is required some specific types of equipment, our rescue team will control the ROV back to the operator's base. When the ROV arrived at the operator's basement, the tether would be detached from the ROV, and the interchangeable tools layer with the equipment required would be attached to the ROV. Meanwhile, the operator would be equipped with a medium connected with the ROV enabling the ROV to follow the operator (the ROV is set to be within 1 meter behind the operator).

Overall, the above message is the whole process of the search and rescue mission.



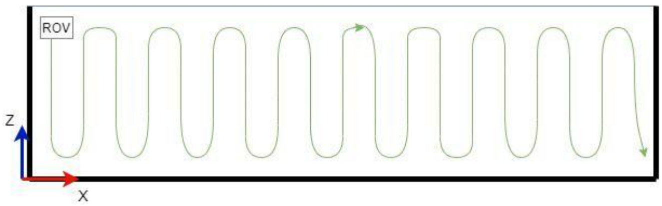


fig.4 above diagram: Aerial view of the autonomous searching route
below diagram: Dive in and float up of the autonomous searching route

Design

This vehicle is a combination of both the ROV and AUV and is expected to have higher compatibility during operation. This vehicle is a modular design in which users can choose to use different compartments according to the situations. Also, the camera system of this vehicle is set up as a 360-degree vision where 4 cameras in the corner and another image recognition camera in front with tilt function can provide the operator with a complete view underwater. With the assistance of a streamlined shell, the ROV can be maneuvering stably in extreme flooding conditions.

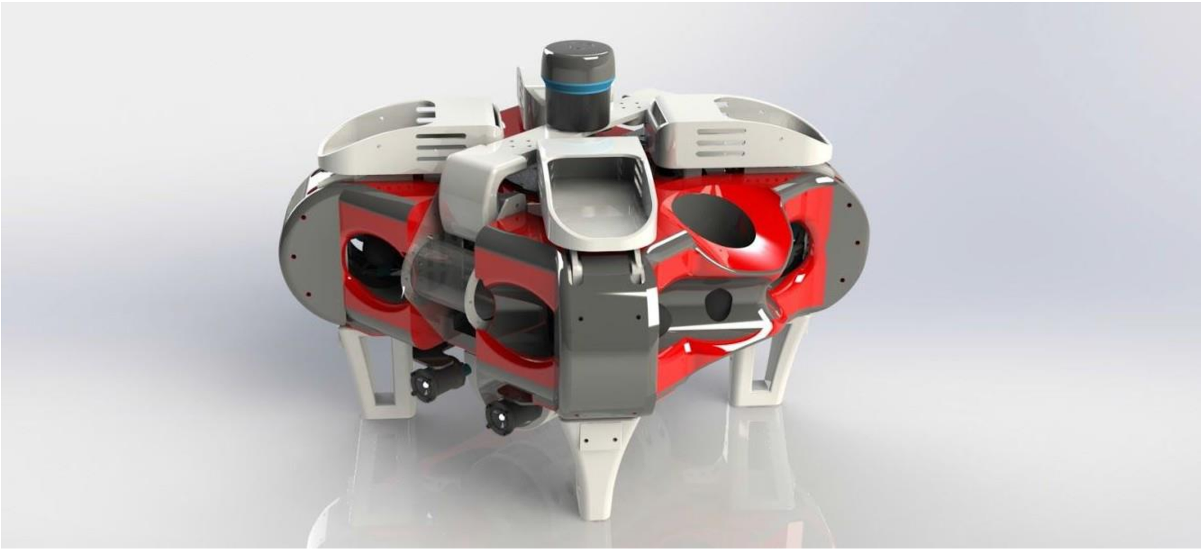


fig.5 The multifunction design of the ROV

1. Electronics system

For different vehicles, the electrical system may have a little difference. Raspberry Pi is used as the main control core in the electrical system of all three designs, with the connection to a Pixhawk Flight controller controlling the thrusters and electronic tools. Furthermore, the wired vehicle is fitted with a camera system with 5 cameras, respectively a low-light USB camera and 4 waterproofed fisheye cameras. Below (Fig. 4) is the Planned System Integration Diagram of the first and the third vehicle.

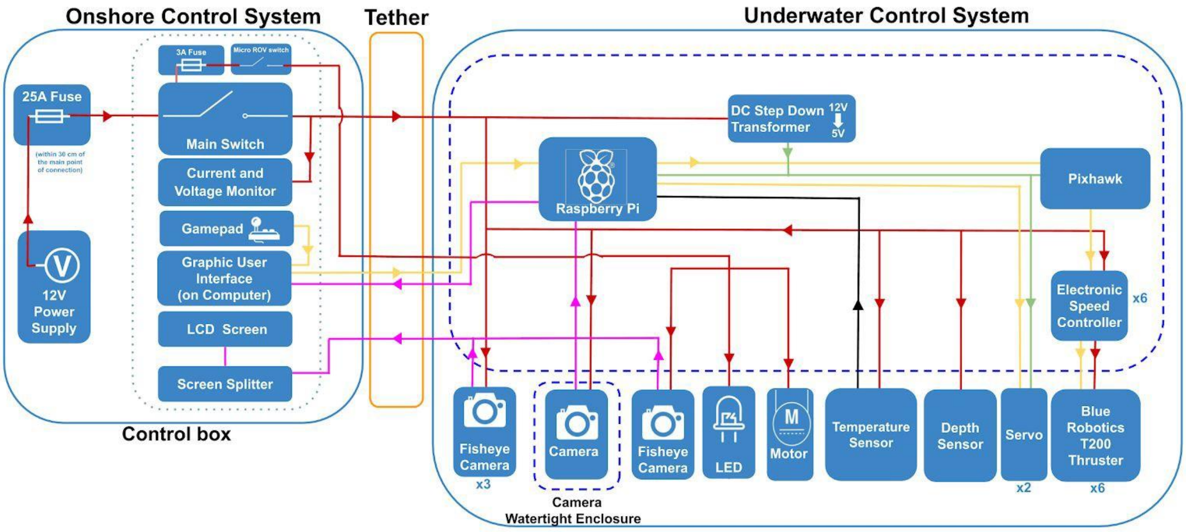


fig.6 Planned System Integration Diagram (SID)

2. Detachable tether

To achieve the with and without tether operation, a detachable tether is used in this function. We had added a waterproofed quick-release plug that can be attached and detached the tether smoothly. After using the wired mode in the searching process, the operator can quickly detach the tether and combine the interchangeable tools layer to start running the predefined set of wireless operation.

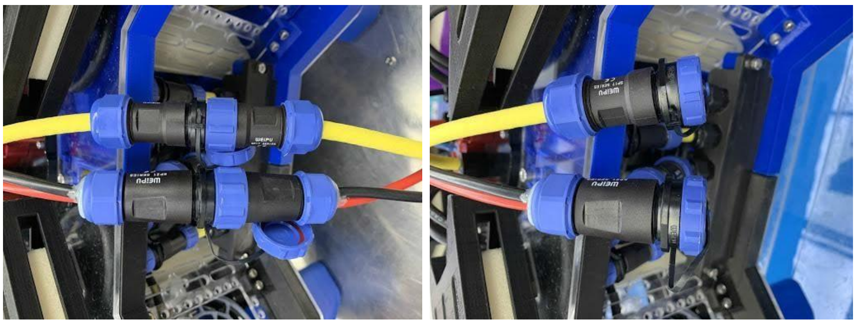


fig.7 Waterproofed quick-release plug

3. Interchangeable tool cassette

The interchangeable tool plate (Fig. 8) is integrated into the ROV for holding more tools for the rescuer. Limited space for tools may hinder the rescue operation. An interchangeable tool plate where users can choose to use different combinations of tools is attached to the bottom of the vehicle. There is a latch on each of the four corners and a mortise on the four feet of the vehicle as a connection point. This tool plate can efficiently assist the SAR process.

fig.8 Interchangeable tool plate CAD

4. Video and Image recognition system

As there are a lot of uncertainties during the underwater SAR process, a specific video system is designed for this vehicle. The third design is equipped with a total of 5 cameras, including a low-light USB camera and 4 fisheye cameras. For SAR usage, a human recognition program can be launched for recognizing humans and underwater objects. An open-source, real-time object detection program called Yolo, downloaded from https://pjreddie.com/darknet/yolo/, was adopted to recognize objects. The functionality and practicality of the software will be tested. Below is the user interface of the video and image recognition system.

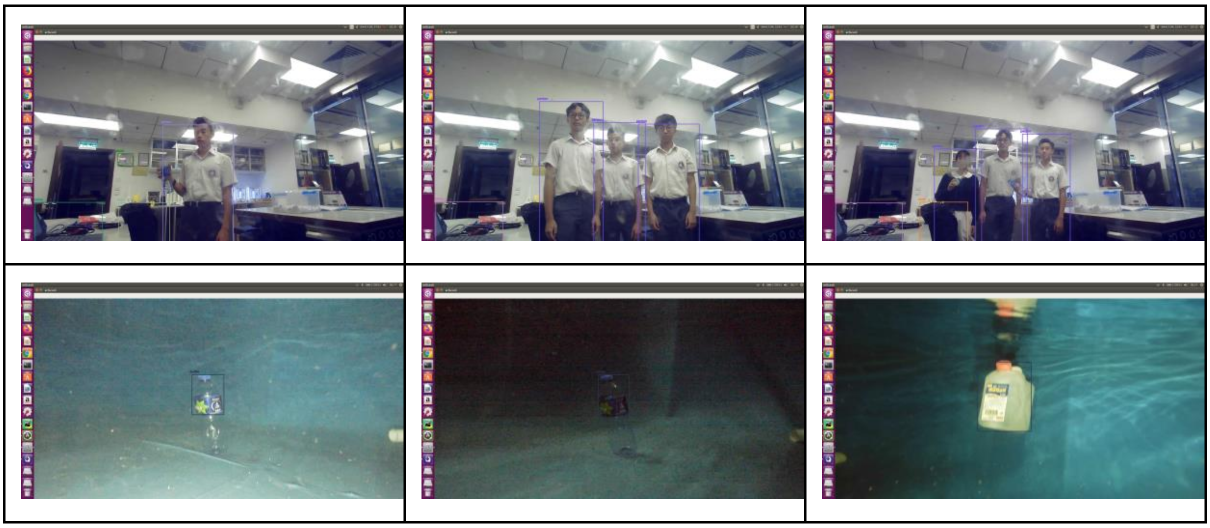


fig.9 Camera of the ROV’s vision in water and off-water

5. Graphic User Interface

One of our outstanding control systems is the GUI implementation. We learned that unfamiliarity with the situation will make the operator having mistakes, so we have utilized a user-friendly interface with additional features that provides information in many aspects, including the video signal from a moveable camera, ROV's movements, depth data, temperature, as well as data from metal detection sensor. On the other hand, the Logitech controller is also connected with the GUI. Our GUI is composed of QGround Control software and a custom-made program. Vital information is shown in the GUI to assist the pilot with a comprehensive view of the ROV performance and mission progress.

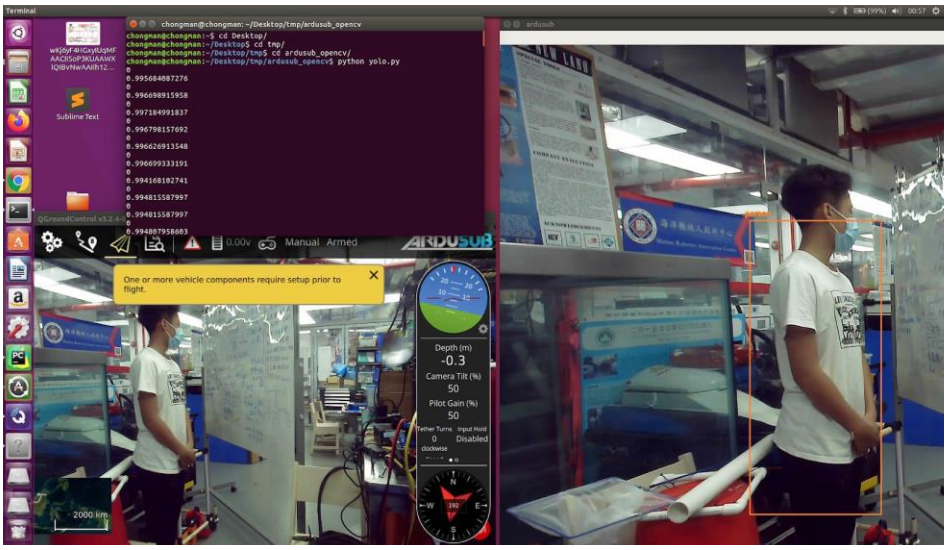


fig.10 The real-time graphical user interface of the ROV

6. Propulsion

To maximize maneuverability while fulfilling the size and weight restrictions, we decide to propel our ROV with six Robotics T200 thrusters. Six thrusters, placed in different degrees, also provide a more comprehensive movement and make the gravity more balanced. As shown in the figure, two thrusters are for vertical movements and the other two pairs are for horizontal movements. Applying four thrusters to the ROV for horizontal movements allows us to move leftward and rightward instead of only turning when using two thrusters, which is a large convenience during the product demonstration. The horizontal thrusters are placed at 45 degrees. In terms of thruster selection, compared to the Seabotix thrusters, T200 thrusters have better stability and are almost two times smaller than SeaBotix thrusters. Moreover, Blue Robotics T200 Thruster requires fewer amps to operate than the Seabotix thruster does. Provided that the same Amps are given, T200 gives a larger thrust than T100 which results in a higher speed.

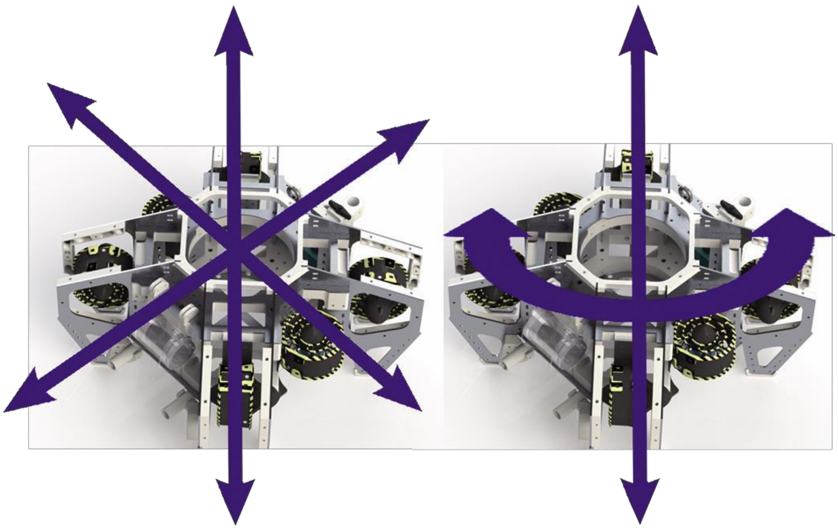


fig.11 Multi-directional movement of the vehicle

7. Low Drag Body Shell

The main principle of designing the ROV is its high mobility and stability, to conduct missions in critical environments, stability is essential to the operation of ROV. The high mobility, on the other hand, improves efficiency when traveling between the mission locations. It is fabricated in ways of 3D printing to ensure its lightweight and low cost. To reduce the load of installation, we separated the shell into ten components. Four of them are fixed along with floating boards inside during installation, while the other six are designed to function as a shroud for protecting the thrusters and cables.

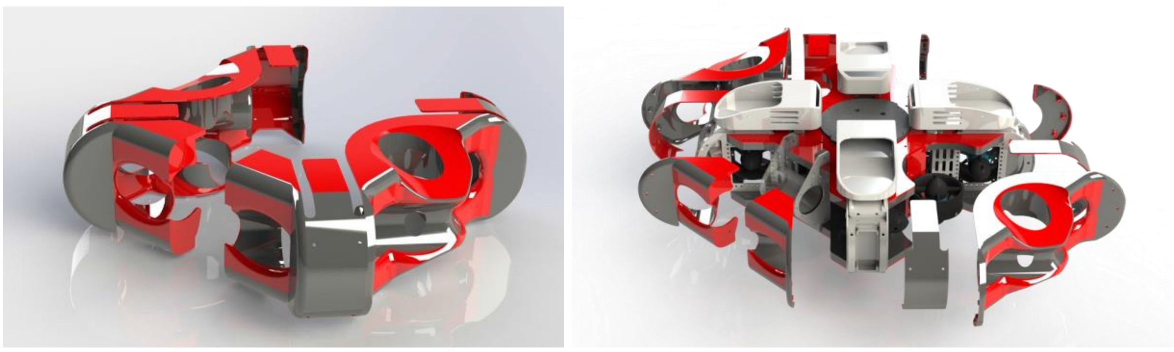


fig.12 The design of low drag streamlined body shell

Testing and Experiment

Based on the previous three-year-period of development, we have performed the following five main experiments in the lab for adequate preparation and physical analysis of the ROV.

1. Flow simulation

There are many sorts of designs in ROV that can achieve the same performance. However, the resources are limited in our lab. Therefore, we need to opt for the best structure of the design in ROV. Besides, the position of the thruster is one of the main aspects.

To use the least resources to reach equal performance, we have decided to use six thrusters in the ROV. With two of them controlling the depth, and four of them in the horizontal plane.

Analyzing the vertical plane is not a big deal. However, it is a bit tricky in the horizontal plane. With only four thrusters, the ROV is required to work in all directions in the horizontal plane. Hence, the team decided to arrange the four thrusters, into 45 degrees each. The reason for this arrangement is based on the resolution of a force, with this decomposition and the angle of 45 degrees, the force of each thruster is divided into two equal forces which are in different directions (90 degrees). After decomposing each thruster, it is amazing to note that somehow the forces are offset and remain four forces in the same direction.

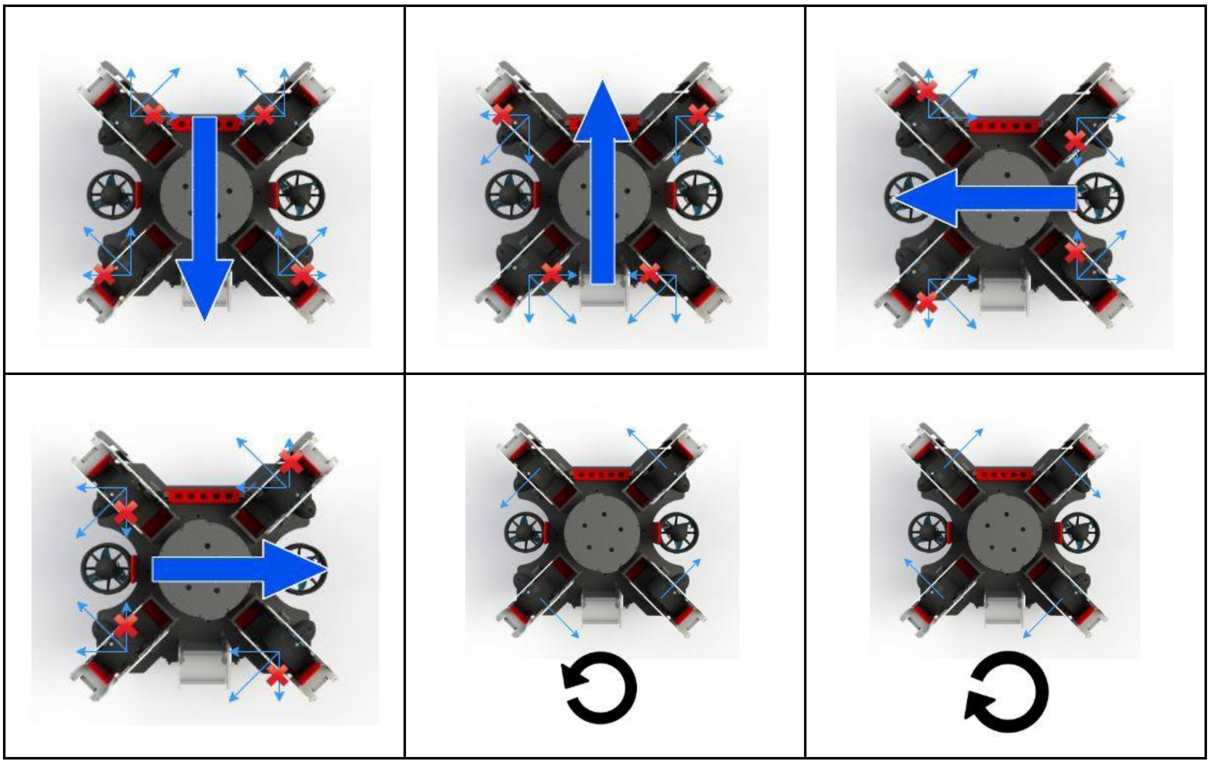


fig.13 The arrangement of thrusters leading to the multi-directional movement of the ROV

2. Light lux experiments

The LED lights intensity play an important role in the ROV. The visibility in the water of the flooding condition without light is less than 0.1 meter, it means that the rescue team can nearly see nothing in the water. However, with the LED lights, the operator is able to see a 1-meter range in the water in the condition of absolute darkness.

This experiment was done in a 3m*2m pool in the lab. In order to test the light lux visibility, the lights in the lab were all turned off, and also we have covered the upper part of the pool with some wooden boards. During the experiment, the ROV was able to see nothing without the assistance of the LED lights. After the team turned on the lights, the team was able to control the ROV to various locations precisely with a visibility of 1.5 meters.

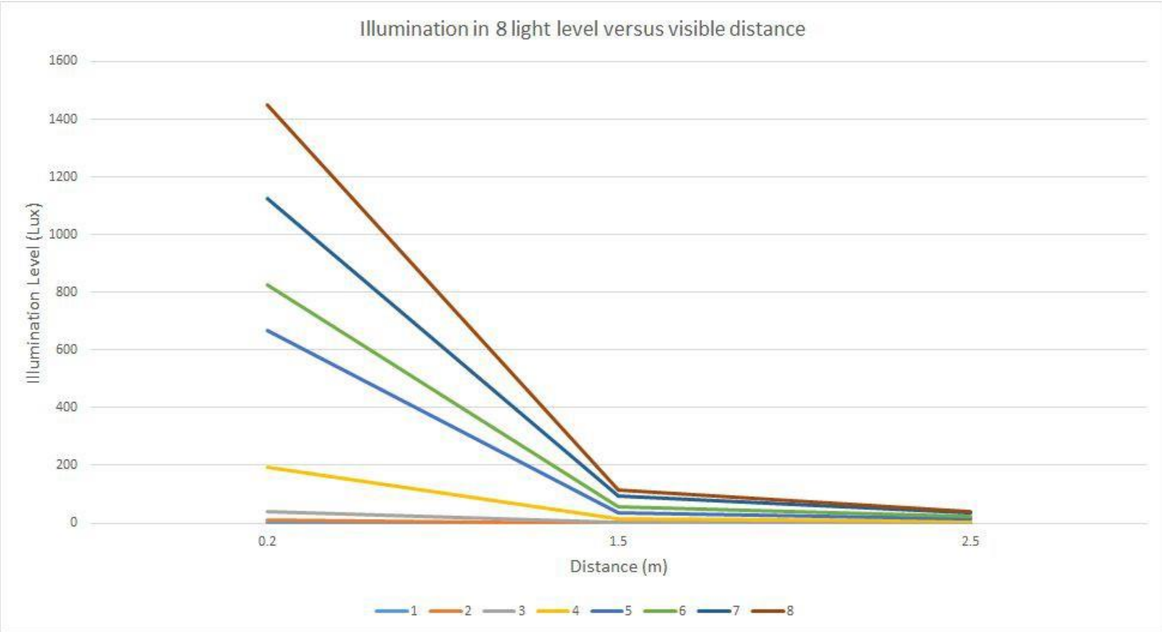


fig.14 The visibility performance through the camera with 8 adjustment of the luminosity of the LED lights

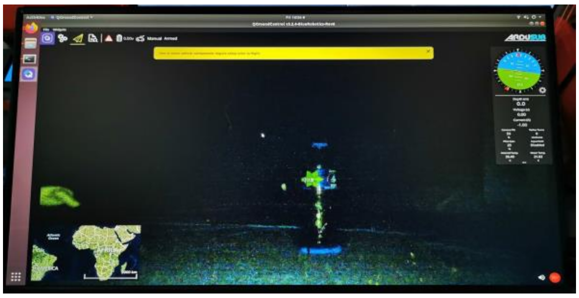


fig.15 In the condition when LED lights were turned off

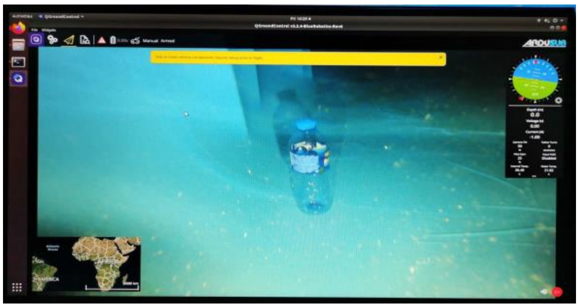


fig.16 In the condition when LED lights were turned on

3. Velocity

The speed of the ROV is also an indispensable factor during the "search and rescue" mission. The ROV will be of no use if it is too slow. The experiment was performed in two places, in the lab, and in the lakeside. The fastest speed which the ROV can reach now is 0.497 m/s, the basic speed of the ROV is about 0.3 m/s.

In the future, we aim to reduce the weight of the ROV by using other materials and a smaller structural design.

The speed of a flash flood is approximately 2.7 m/s. To ensure that our vehicle can work at such a flow speed, a flow simulation of the situation was created by using SolidWorks™.

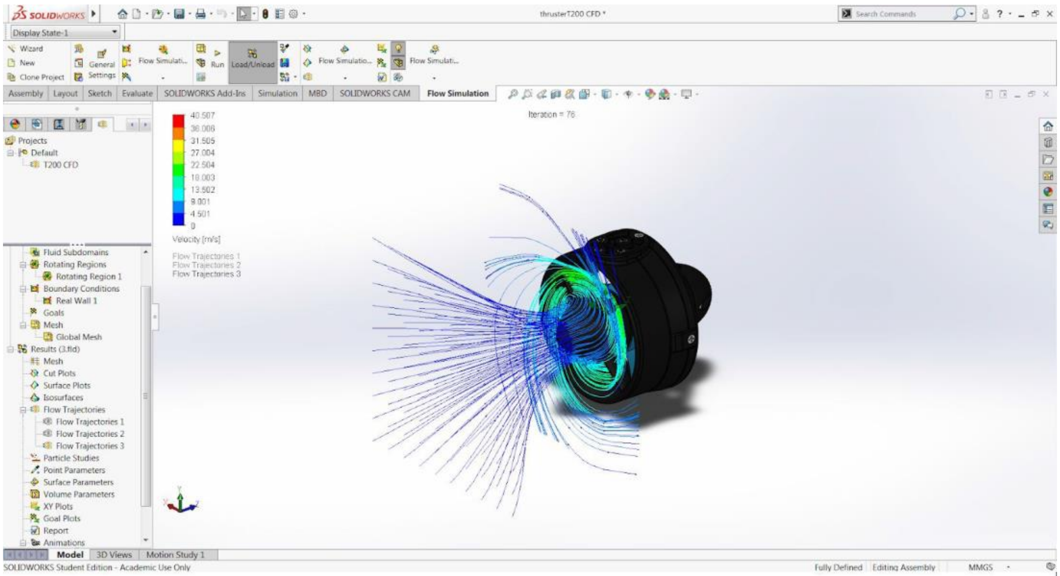


fig.17 Flow simulation in SolidWorks of the thruster

4. Buoyancy

In the Buoyancy test, our aim is to make the ROV be able to stay in the same position in the water or even floating itself back to the surface. Therefore, the team needed to decide whether the size and volume of the buoys should be arranged in the ROV.

In the calculations of the buoyancy, we found that we need 18N of buoyancy in order to make the ROV's weight lower than the buoyancy. In the deployment, the team arranged 18 kickboards providing 1N of buoyancy each.

Buoyancy calculation:

1. Give: Vehicle weight(11kg), Underwater Vehicle weight(2.2kg)

   $\because F_{(vehicle\ weight)} = G - F'_{(underwater\ weight)}$

   G1: 11.0 * 10 = 110N
   F1' : 2.2 * 10 = 22N
   F (water) : 110 - 22 = **88N**

2. Give: Vehicle weight(with kickboard 11.8kg), Underwater Vehicle weight(1.8kg)

   G2: 11.8 * 10 = 118N
   F2' : 1.8 * 10 = 18N
   F (water + kickboard) : 118 - 18 = **100N**

   ∴ F2 - F1 = F of kickboard = 100N - 88N = **12N**
   F of kickboard / number of kickboards = F of each kickboard = 12N / 12 = **1N**

   Maximum number of kickboards * F of each kickboard = 36 * 1 = 36N
   F of water + F of kickboards Maximum = 88N + 36N = 134N
   Maximum G - G = 134 - 118 = 16N = **1.6kg**

   ∴ We are allowed to add <u>1.6kg</u> of tools to the vehicle.

5. Movement stability test

We have various developments of the low drag body shell of the ROV affecting the stability and also the weight. With the addition of the shell, it is evident that the stability of the ROV is much better than before. By contrast, it is a little bit heavier with a weight of 1.1kg. In addition, the team has added two buoys to overcome the weight of the body shell. Hence, the ROV is able to maneuver stably in the water.

In the following table demonstrated the stability of the ROV, we had tested both with and without the low drag body shell. It is clear from the comparison table that we can determine the stability of the ROV by comparing the amplitude of the body movement.

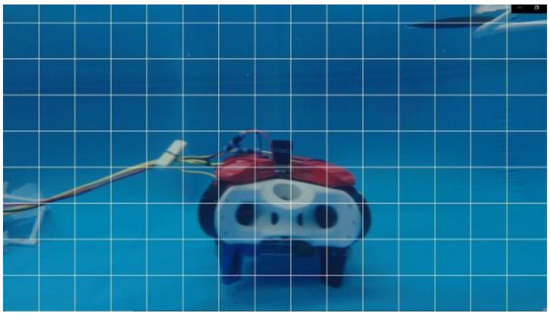
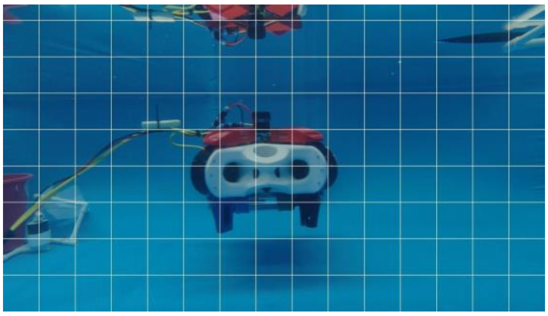
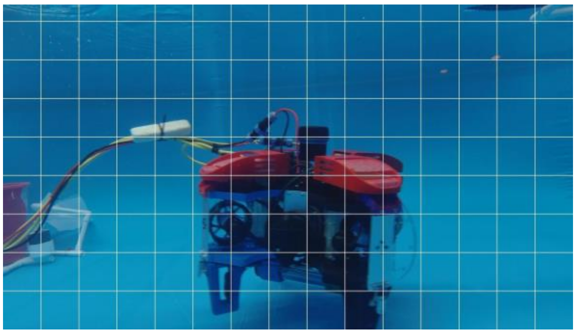
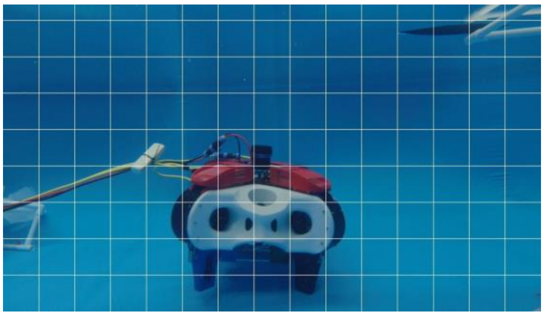
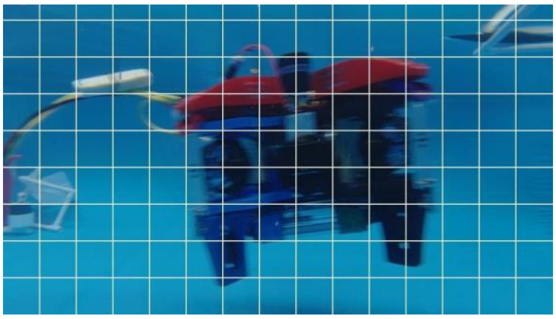
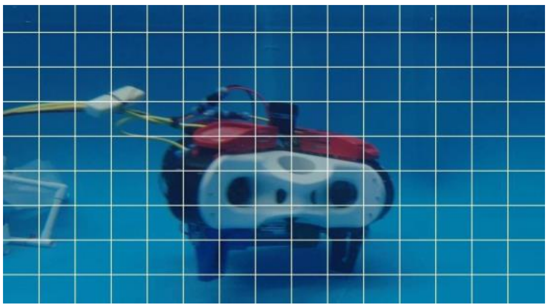
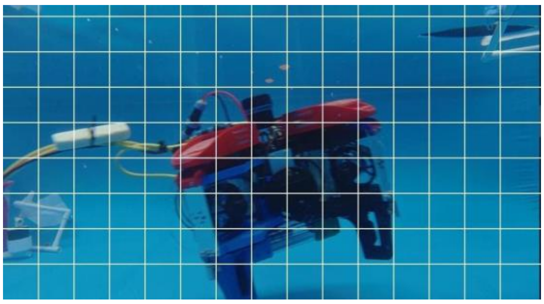
With Low Drag Body Shell	Without Low Drag Body Shell
	
	
	
	

fig.18 Movement stability comparison

Performance

The above experiments are all the preparation for this real environment situation test. The team has selected two destinations in Macau, *Picnic Park Dam Of Ká-Hó,* and *Praca do Lago Sai Van* for the ROV performance test. Both of the locations had demonstrated the ROV was fully controlled by the operator.

However, the actual on site testing which we had performed in the two lakeside did not fully fit the real flooding condition. Therefore, our aim in the future is planning to simulate the real flooding conditions with different assistance arrangements such as wind generation and obstacles.

fig.19 Performance in an actual on site testing environment

Conclusion and future work

We have achieved our design intent on multi-function operation with technologies implementation. The ROV was operated through the control station graphical user interface with the assistance from signal processing in image recognition and sonar scanning capabilities.

This project undoubtedly will be in continuous development. The next step of the project will focus mainly on three perspectives. Firstly is the balance of weight and the stability of the ROV. In the future, the team aims to reduce the weight of the ROV and at the same time with high stability in operation. Secondly is the object detection of the ROV. The visibility of 1 meter down in the water is not enough to deploy object detection with it. Therefore, we have two methods in order to achieve this function, OpenCV and LED light. OpenCV can adjust the captured photo into a detectable condition for object detection. On the other hand, we can opt for a LED light with stronger luminosity to achieve equal performance. Last but not least, the authentic test in simulated flooding conditions. We aim to use different assistance such as wind engines and obstacles to achieve the most familiar simulation as the flooding condition.

In conclusion, flooding conditions are in a drastically increasing trend due to the irreversible condition of global warming. The team anticipate this continuous project development will provide a functional and rapid "Search and Rescue" vehicle deployment under the extreme weather flooding conditions.

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【評語】100039

This project is aimed to contemplate the design of a multifunctional intelligent autonomous underwater remote operating vehicle that could perform “Search and Rescue” in flooding. The integration with the system, video/image recognition system, graphic user interface, and movement are quite well-discussed. However, the movement of the vehicle under the water flow is dynamic and is not easy to be predicted. How will you overcome the issue of clarity in the flood? How does the work of LEDs in flooding conditions?

Besides, this underwater remote operating vehicle (ROV) is designed with and without tethered operation. The operator can control the ROV from the real-time first-person view in a graphical user interface combined with sonar and object detection function when the tether is attached. For the purpose of search and rescue, the control tether with fiber optic lighting cable establishes a guided link medium between the possible search victim location and the rescue team. When the tether is detached, rapid deployment by a predefined set of instructions to achieve further operation range.