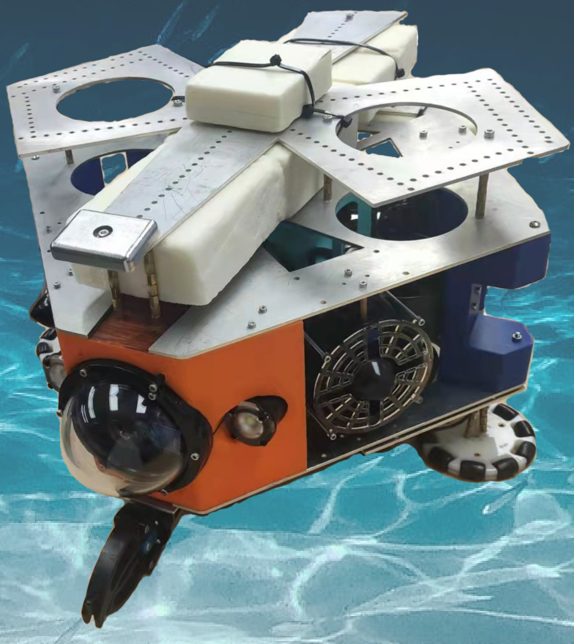
Aquarius

Technical Documentation

Pui Ching Middle School Macau

Macau SAR



1 Abstract

Aquarius is a team of 6 passionate students along with mentors from the Macau Pui Ching Middle School. Our team has been working with Remotely Operated Vehicles(ROV) that can execute missions such as underwater rescue or repair missions since 2018.

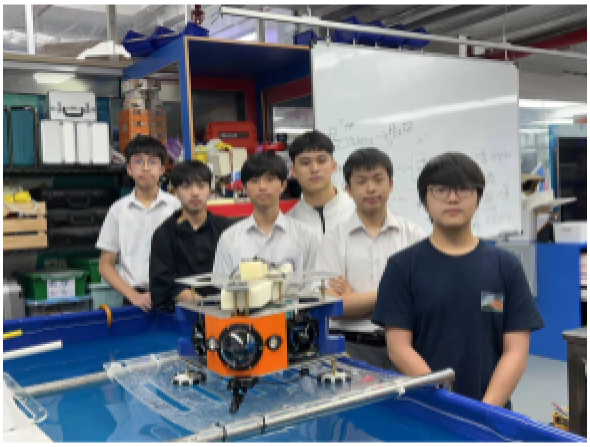


Figure 1, Aquarius team

Figure 2, Artmeis

Artemis is the third ROV designed by Aquarius on the request for 2022 MATE ROV Competition to support marine renewable energy, blue carbon and offshore aquaculture. Its dimension is about 510 mm in length and 480 mm in width and 340 mm in height. Also our ROV is weighted 11.5 kg which meets the size and weight restrictions. The robot is equipped with six brushless thrusters, an aluminum frame, LED lights, a low-light 1080p 30fps camera and a multifunctional robotic arm.

Moreover, its rhomic design contributes less drag force underwater. With these features, Artemis is ready to execute tasks such as grabbing and carrying random items and image recognition using the camera underwater. Most of the structural components are self-made which result in a relatively low cost and enables customization for different missions. Furthermore, its structure mixes the use of 3mm aluminum plates and 3D printed which construct a firm framework. Components such as Electronics and Thruster are widely reused from our previous ROV since those components are still in good condition and reduce costs. Artemis also provides sufficient space for the placement for the tools in the future.

This document will be explaining the project of Aquarius; Artemis in detail.

2 Designing Rationale

2.1 Design Philosophy

Artemis is the third remotely operated vehicle Aquarius has manufactured and spent time on. We have learned a lot from our previous process of developing a ROV. After months of brainstorming, we decided to have a brand new design compared to our previous ROV with improvements.

Our main goal for Artemis is stability and mobility underwater. We aimed to design a robot that is stable to operate efficiently underwater. Firstly, the rhombic design of the frame contributes less drag force underwater, and a solid connection with the use of a screw between the top frame and the bottom frame connected to 3 different 3D-printed components. Secondly, ArduSub is used as the control system of Artemis with QGroundControl as its base station software. Thirdly, Raspberry Pi 3 and Pixhawk are the two main hardware used in Artemis.

All these rehabilitate benefits of high stability, mobility, and surveillance ability underwater. We designed and executed the Artemis with these philosophies.

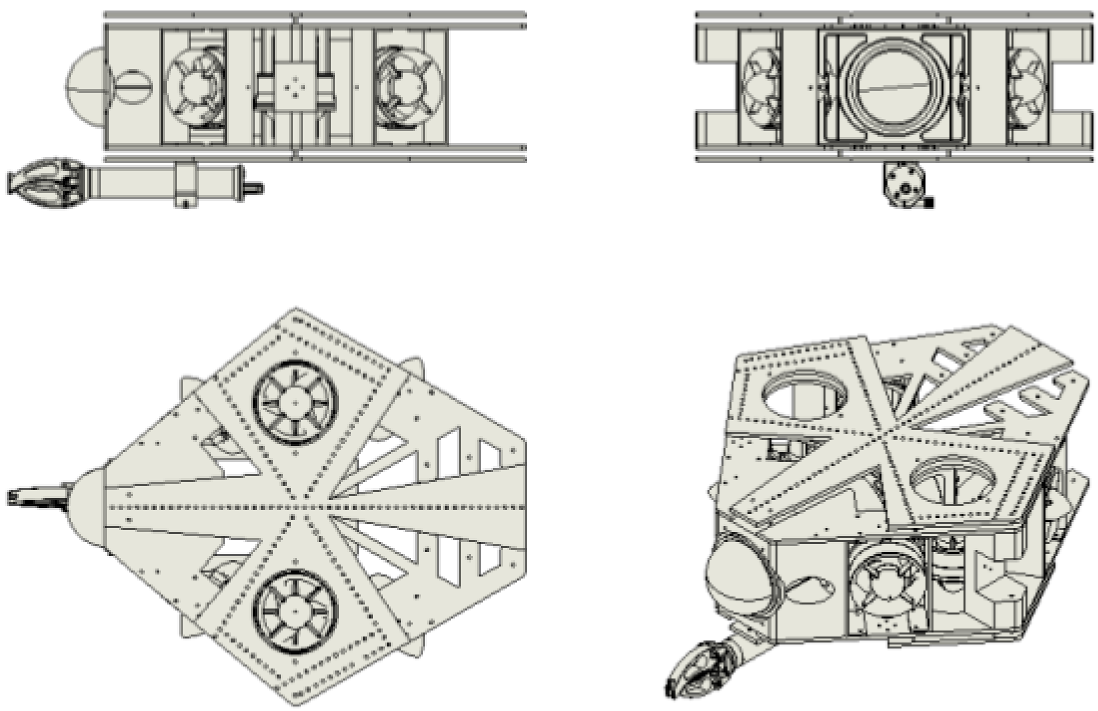


Figure 3, drawings of Artemis

2.2 Material Choice

The choice of material was difficult for our frame. Our initial choice of material is all aluminum and all PLA 3D-printed plastic. PLA is chosen as it is more environmentally friendly, in addition to its low cost and ease of use. However, using just 3D printed components is too fragile, and lightweight and hard materials are considered. The research was done and our conclusion is that 6061 aluminum plates are the ideal material for building a stable and hard frame. Aluminum plate can be easily managed and handled in the CNC machine in our workshop as it is malleable.

2.3 Waterproof

Electronic components are housed in a watertight enclosure that makes the components reusable and maintenance-friendly. This design makes our ROV easier to maintain than epoxy resin-coated electronic components. Furthermore, opting for commercially supplied watertight enclosures is more cost-effective and reliable. It is more budget-saving and dependable than building a custom enclosure. Therefore, a 4" waterproof enclosure produced by BlueRobotics is more than suitable for our needs. On top of that, a doom-ended cap is customized for the position of our camera.

2.4 Buoyancy

To ensure the driver masters the ROV, our goal for ROV buoyancy is to keep the ROV upright and maintain its depth. To achieve this, the average density needs to be as close as possible to that of water (neutral buoyancy). High-density polyurethane foam (HDPE) is used to provide upward force, counteracting the ROV's weight in water by trapping less dense air in its structure. The foam is cut into 44*12cm standard-size blocks that can be mounted to the center of the ROV roof to provide a high buoyancy center. Adjust buoyancy by adding or removing foam blocks.

2.5 Propulsion

In order to complete tasks efficiently, we provided 6 thrusters to be our propulsion system. The thrusters' composition is critical to completing the task successfully. Artemis has six thrusters: four for horizontal movement and two for vertical movement. The horizontal thrusters are angled at about 45 degrees to give maximum thrust and allow Artemis to move quickly and efficiently. Furthermore, Artemis had to go from one side of the board to the other side in order to follow the horizontal tangent, and the thrusters were set at a 45-degree angle, allowing Artemis to move to the left and right without spinning. We decided not to make a thruster since the BlueRobotics T-200 thruster has superior stability and a smaller footprint than equivalent market devices. Furthermore, the BlueRobotics T-200 thruster runs on very little electricity. The T200 plainly has greater push than the T100 at the same current, resulting in higher speeds. As a result, the T-200 thruster from BlueRobotics was chosen as our propulsion system.

2.6 Tether

As Artemis requires 12 volts of power and two cables that are able to transport video signals and communicate with underwater control systems, the tether of it needs a set of 10 AWG cables (one in black and one in white as shown). Furthermore, it contains two different ethernet cables. One of them is used to communicate between onshore and offshore control systems, which in our ROV is a RaspberryPi. Another ethernet cable is used to connect the underwater camera system and the monitor in the control box. We wrapped the set of power cable and 2 ethernet cable with a cable braided sleeve for further protection.

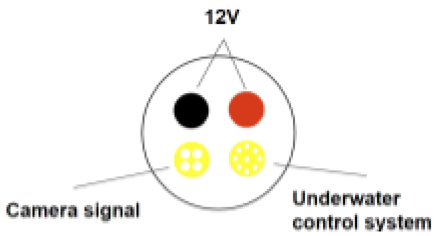


Figure 4, Inside of Tether

As the mission required moving a long distance, we made our tether 25 meters long. Therefore, a wire spool is used to keep our tether in the tide.

2.7 SID

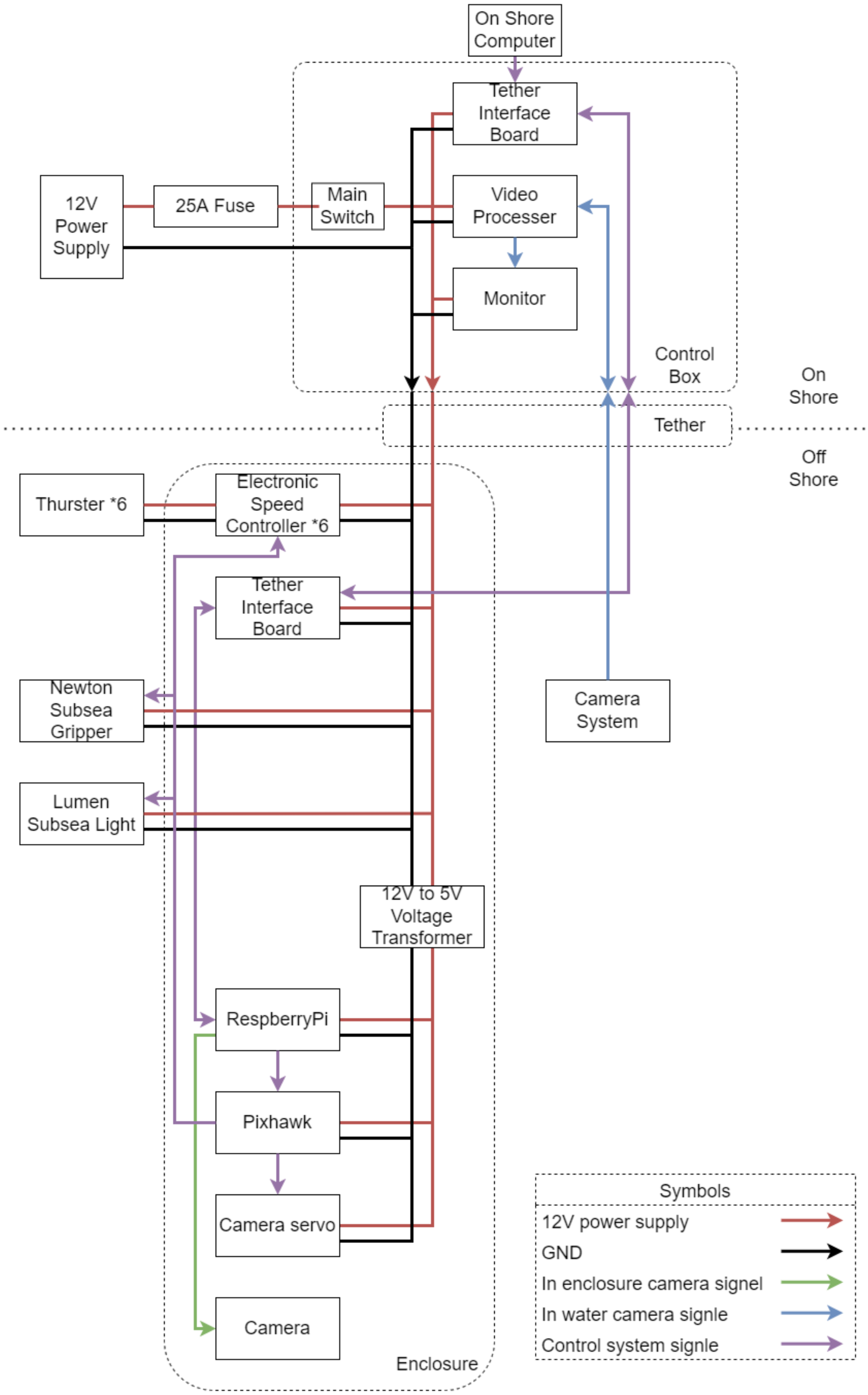


Figure 5, SID of Artemis

3 System Architecture

3.1 Operating System

The control box of Artemis consists of a 15.6" monitor, where signals from four cameras are displayed so that the pilot can take them as reference to monitor different angles of the Arthemis when executing different tasks and missions. In addition, a screen splitter is used for amplifying the camera signals while ensuring their quality. All electrical circuits are positioned at the bottom of the control box. A joystick is used for the pilot to command Artemis in a manual way.

We opted for ArduSub as our operation as ArduSub is already a packaged commercial use under robotic operating systems which perform better. Furthermore, the ArduSub system contains a feature that allows us to import python codes and execute on our ROV.

3.2 Underwater Electronics System

As our ROV design is different from our previous one, the watertight enclosure changed from a wider one to a thinner, longer one. Therefore, our underwater electronics system has to be changed. It contains a main board with 2 layers and a vertical board (as figure 6 shown).

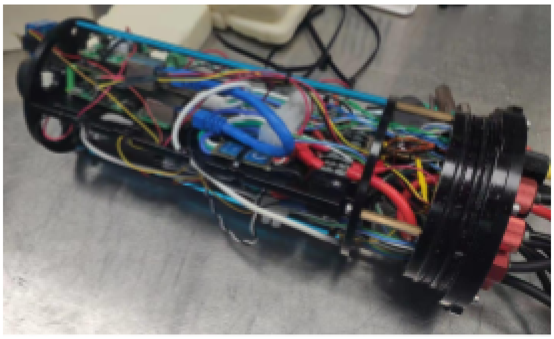


Figure 6, Inside of watertight enclosure

The main board is used as a bone of our underwater electronics system. As we opted for ArduSub as an operation system, a Pixhawk is stabilized on the main board. A Raspberry Pi and a tether interface board are used to be the operating systems and communicating systems.

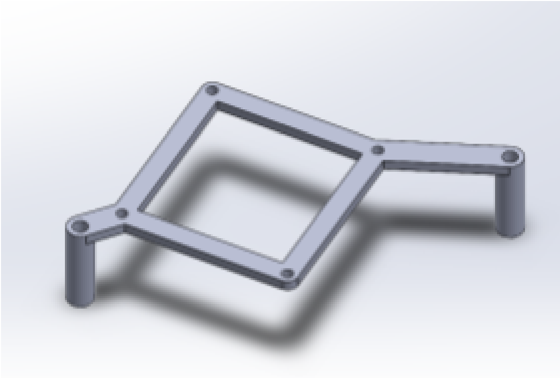


Figure 7, Tether interface board connector

Yet, these two boards have no connecting point, so we make a mounting base with a 3D piece as figure 7 shown. Our underwater electronics system contains 6 electronic speed controllers to take control on our 6 different thrusters.

To make the 12V power supply look organized, we designed a power hub in our underwater electronics system. Good to mention that we designed a vertical board to mount the USB camera at the front of our ROV, allowing a best view for piloting.

3.3 Camera System

As the pilot may not observe the pool while doing a mission, a USB camera is placed inside the enclosure. Therefore, our ROV design put the watertight enclosure to the front to get the best view for both our pilot and our computer vision systems.

To furthermore support on completing missions such as pulling pins in task 1 etc, a waterproof camera is fixed at the red point and pointing toward the grip as the figure shown.

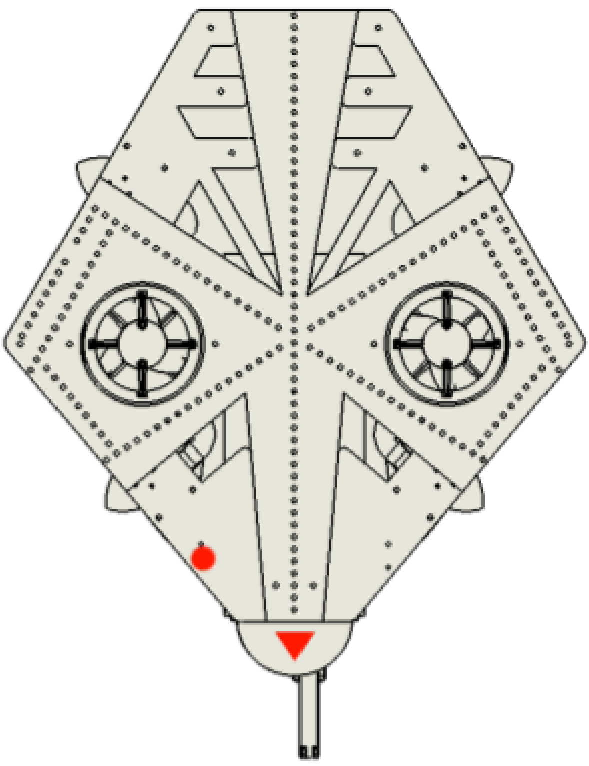


Figure 8, Camera position of Artemis

3.5 Mission Specifics

3.5.1 Video Recognition System

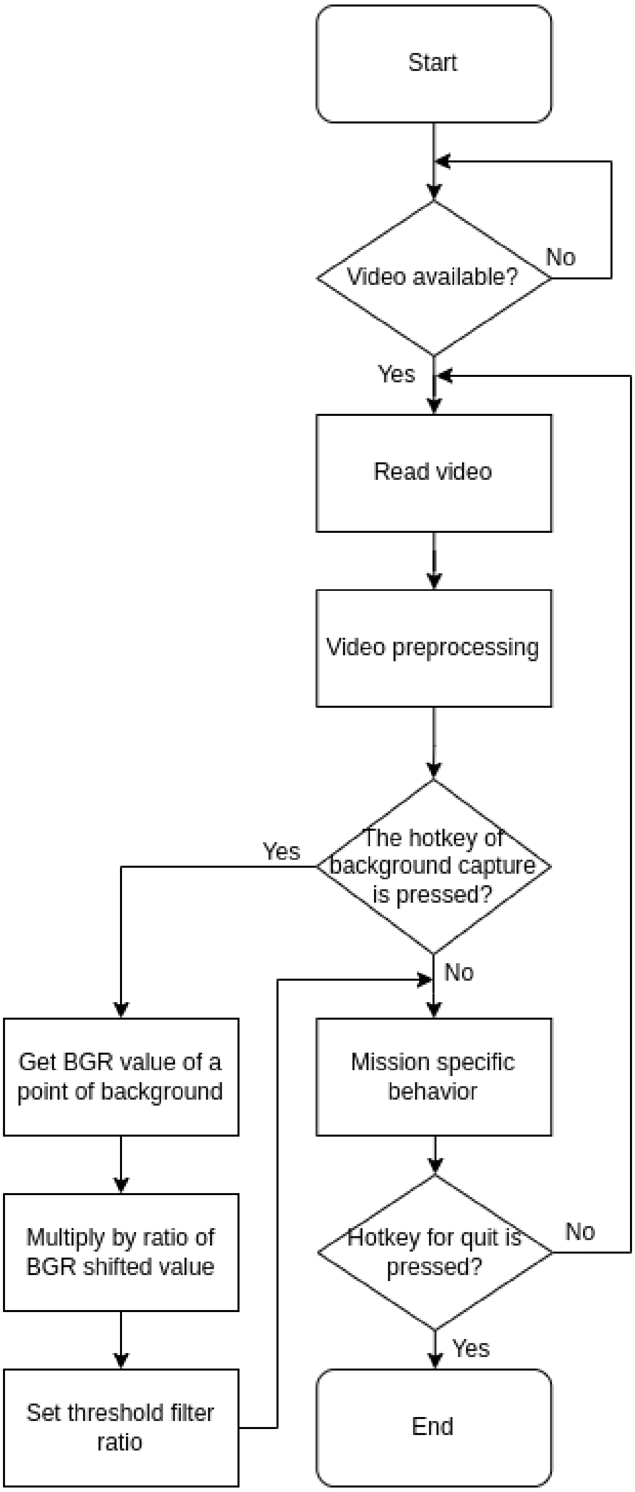


Figure 9, flow chart of video recognizing system

To deal with the missions, we set up an image recognition system with the use of Python and OpenCV. We read video data from the USB camera at the head of the ROV, then the collected video is preprocessed including resizing and blurring, in order to format the video and reduce the noises.

Then, to prepare for the thresholding in the mission specific behavior, we create a background capture function to calculate the threshold filter ratio that is used in the calculation of thresholds of the 3 color channels.

The background is captured by pressing “b” on the keyboard at the onshore operation system. Then The BGR value of a specific point on the video is collected.

The thresholds are calculated by multiplying the BGR value of the captured background by the ratio of BGR shifted value, which is obtained in the experiment in our lab, finding the relationship between background color and threshold values.

3.5.2 Inspecting Line

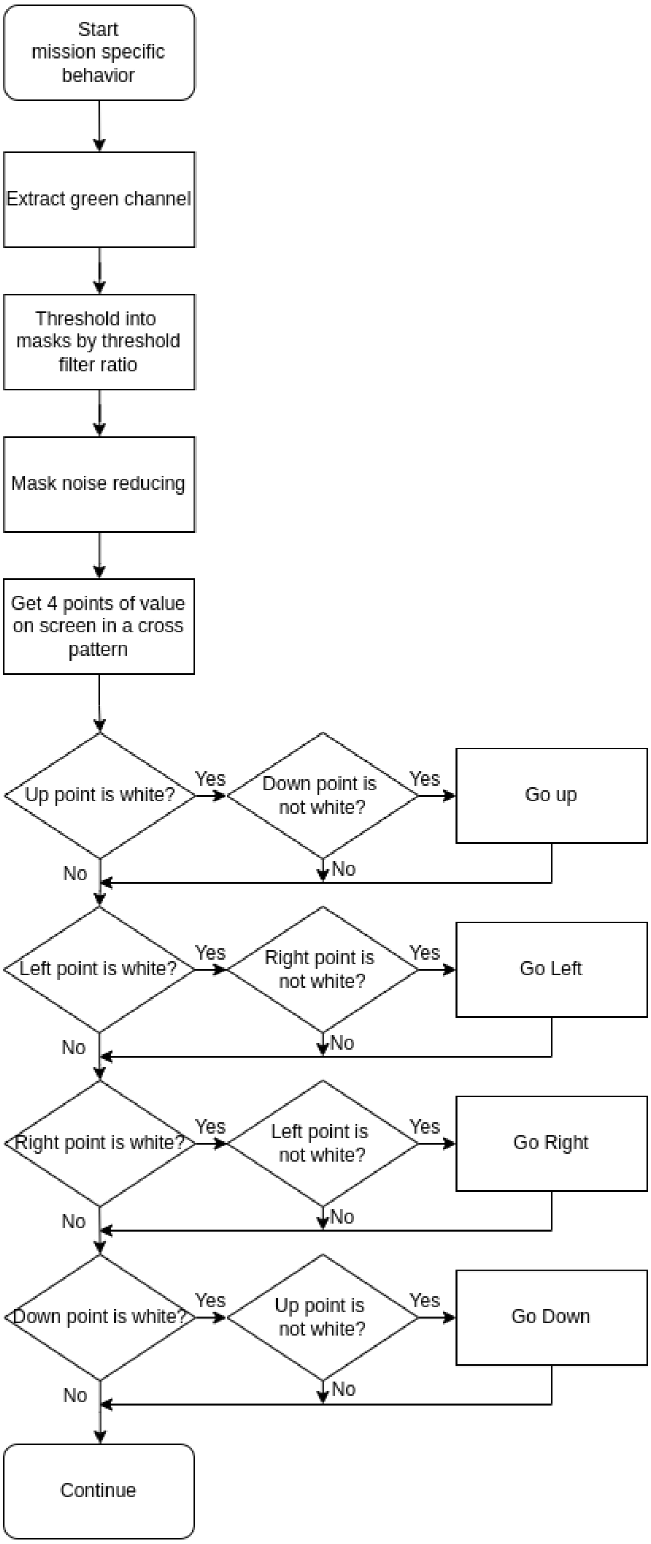


Figure 10, flow chart of line inspecting system

The Inspecting Line System is implemented in the mission specific behavior block mentioned in the Video Recognition System.

The green channel is extracted and is threshold into mask by the threshold filter ratio calculated in the background capture function. Then, it is eroded and dilated using a kernel to reduce the white dots and small noise caused by thresholding, in order to improve our performance.

We only extract the green channel as the background of the red rope is white, which means that the red value of the background is bigger than the red value of the rope most of the time. In addition, the background underwater is mostly blue, so blue is also not a good choice for identifying the red rope.

After obtaining the mask, we collect the color value of the four specific points, which are up, left, right and down points. The ROV will change its movement direction when that direction is white and the opposite direction is black, which means that when both points are white, the ROV won't change direction, allowing it to follow the line until it leaves the line.

3.5.3 Measure Fish Size

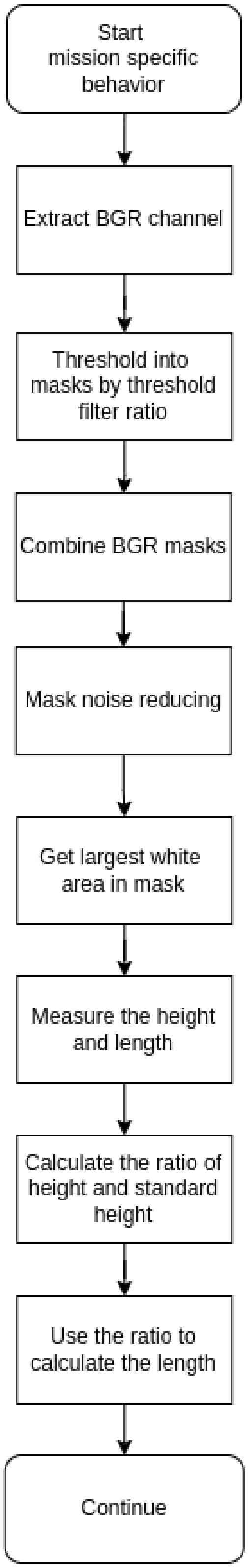


Figure 11, flow chart of fish size measuring system

The Fish Length Measuring System is also implemented in the mission specific behavior block mentioned in the Video Recognition System.

The BGR channels are extracted and processed using the method mentioned in The Inspecting Line System.

After obtaining the masks of the 3 colors, we combine it using the cv2 add function, combining the white area on each mask into one mask. Then erode and dilate it with a kernel to reduce noises.

After that, we have got two white areas which are the head and body of the fish. However, the connecting pipe of the two fish parts is covered with blue floaty, which is hard to mask out from the background. Therefore, we put a white block on the video for the pilot to cover the pipe with, so that the two white areas can be connected and captured.

Then, we use the boundingRect function in cv2 to get the height and width of the white area. We divide the height value by the standard height (13.5cm) of the fish in order to get the ratio of captured area’s and fish’s standard size.

Last, we multiply the width of the white area by the calculated ratio to get the width of the fish.

The fish capturing method is also used in the fish detecting mission, and a similar method is used in recognizing buttons in the pushing button mission.

4 Finance

Our budget of the project was made based on the expenses of our last year ROV. According to our previous experience, the only source of income comes from our school, the Macau Pui Ching Middle School. With limited income, each of the expenditures must be reasonably priced and stick to our budget .In each purchase, price comparison is important in order to save our budget, we choose the most suitable product at the lowest cost. On the other hand, to keep up with our budget and minimize our project cost, an evaluation of the pros and cons of the need to purchase, design, build or reuse is made for each component for making decisions.

4.1 New VS Reused Components

Artemis is our third ROV that we designed by ourselves. To make use of previous components and reduce the cost of this new designed ROV, we opted for a more environmentally friendly option. We reused most of the old components, most of them are in good condition and functioning correctly, especially on electronics. Although some of them are not functioning normally, we tried to repair them. This action not only saves the environment, it also can reduce the budget of making a new ROV.

4.2 In-House Built Vs Commercial Components

Our workshop, Fablab Pui Ching — Macau, is a well-developed laboratory for us to manufacture our ROV. In such a good environment, teammates have the opportunity to use varied machines. Also, Pui Ching Middle School targets science and engineering. Therefore, We can learn how to operate those machines safely in the school curriculum. For example, teammates are trained to use machines such as the 3D printers, the CNC machine, and the laser cutter under strict safety protocols, hence many of the components are managed in and out. The aluminum plates are cut out in the CNC machine while the 3D printed parts of the body of the ROV are manufactured in the 3D printers in the lab.

4.3 Project Costing

Project Costing						Reporting Period
School Name:			Pui Ching Middle School			From 08/2021
Instructor:			Thomas Lao			To: 06/2022
Funds:						
Date	Type	Category	Expense	Description	Amount(USD)	Running Balance(USD)
08/2021	Cash Donated	Funds		Funds from school	$3,250.00	$ 3,250.00
09/2021	Re-used	Hardware/ Electronics	Electronic enclosure	BlueROV2 Electronics Enclosure	$1,590.00	$3,250.00
09/2021	Purchased	Electronics	Pixhawk	Pixhawk 2.4.8	$78.00	$3,172.00
9/2021	Purchased	Electronics	ESC	Blue Robotics Basic ESC*2	$72.00	$3,100.00
9/2021	Purchased	Electronics	Fuse		$5.00	$3,095.00
9/2021	Re-used	Hardware	Thrusters	Blue Robotics T200 Thrusters	$1,015.00	$3,095.00
10/2021	Parts Donated	Hardware	PLA filaments, Screws, Aluminum sheet	Parts donated by school	$60.00	$3,095.00

10/2021	Re-used	Electronics	LED, Sensors, Network cable		$333.0	$3,095.00
10/2021	Re-used	Electronics	Cameras, Control box, Monitor		$222.0	$3,095.00
12/2021	Re-used	Electronics	Joystick	Logitech Extreme 3D PRO Joystick	$39.99	$3,095.00
12/2021	Parts Donated	Hardware	Acrylic boards	Parts donated by school	$11.16	$3,095.00
12/2021	Parts Donated	Electronics	Anderson Ports, Banana plugs	Parts donated by school	$30.00	$3,095.00
					Total Raised	$3,250.00
					Total Spent	$155.00
					Final Balance	$3,095.00

5 Safety

5.1 Company Safety Attitude

Beside learning experience, a very important thing we value is safety in our company. Our team aims to make a safe work environment so that we can work safely in the lab. Also, we make sure our ROV is safe, which does not include sharp or dangerous materials in order to protect the people or environment that won't be hurt by our ROV. We try our best to create a good safety culture in the company and we promise that we will keep doing better and ensure both us and others' safety at the same time.

5.2 Safety in Workshop

Everyday, we spend a lot of time in our workshop in order to finish our ROV project. Therefore, it is so important to maintain a safe area for us to work. So We set up five rules: first, always turn off the machines when we are not using it, second keep our table clean, especially ensure that there is no water on it, and lastly, we will put on our goggles and gloves when soldering, forth, all tools and gadget must be put back to the original positions. Fifth, we selected a teammate to be the safety manager, who is dedicated to make sure our team finishes all the tasks on the safety checklist. These five rules are established so that we can be protected.

5.3 Safety Features

- Remove sharp edges：sharp edges can cause damage to the creature or objects near it, so all sharpened edges were removed from the design.
- Thruster Shrouds：The shrouds are placed on the thrusters to prevent any object from swirling into the thrusters and damaging it.
- 25A fuse：(approximately 13cm) for overcurrent protection

6 Schedule & Team Organization

6.1 Project Management

Managing time for ROV building is never an easy task besides academic studies and extracurricular classes of team members. So managing an annual time when all team members are available to have meetings, planning, sketching, building and training is challenging, hence good time management skill is essential. Annual meetings are held to allocate new tasks according to their position, and team members are asked to summarize the work they have done each week , so that all team members know the work process. Altogether, we have worked for approximately hours from sketching, planning, building, and training since September 2021.

6.2 Team Organization & Assignments

Aquarius is divided into three departments: Electronics Mechanics department, and ROV operation. Members of each department are responsible for reporting their daily progress to the CEO so as to make sure everyone is in their position and works efficiently. Apart from the CEO, the other posts like safety officer, CTO and QCO are set to tackle other specific tasks such as accounting, technical aspects development and quality control.

7 Critical Analysis

7.1 Testing and Troubleshooting

Our team set a guideline which guided us on what we should do before piloting as figure 12 shown.

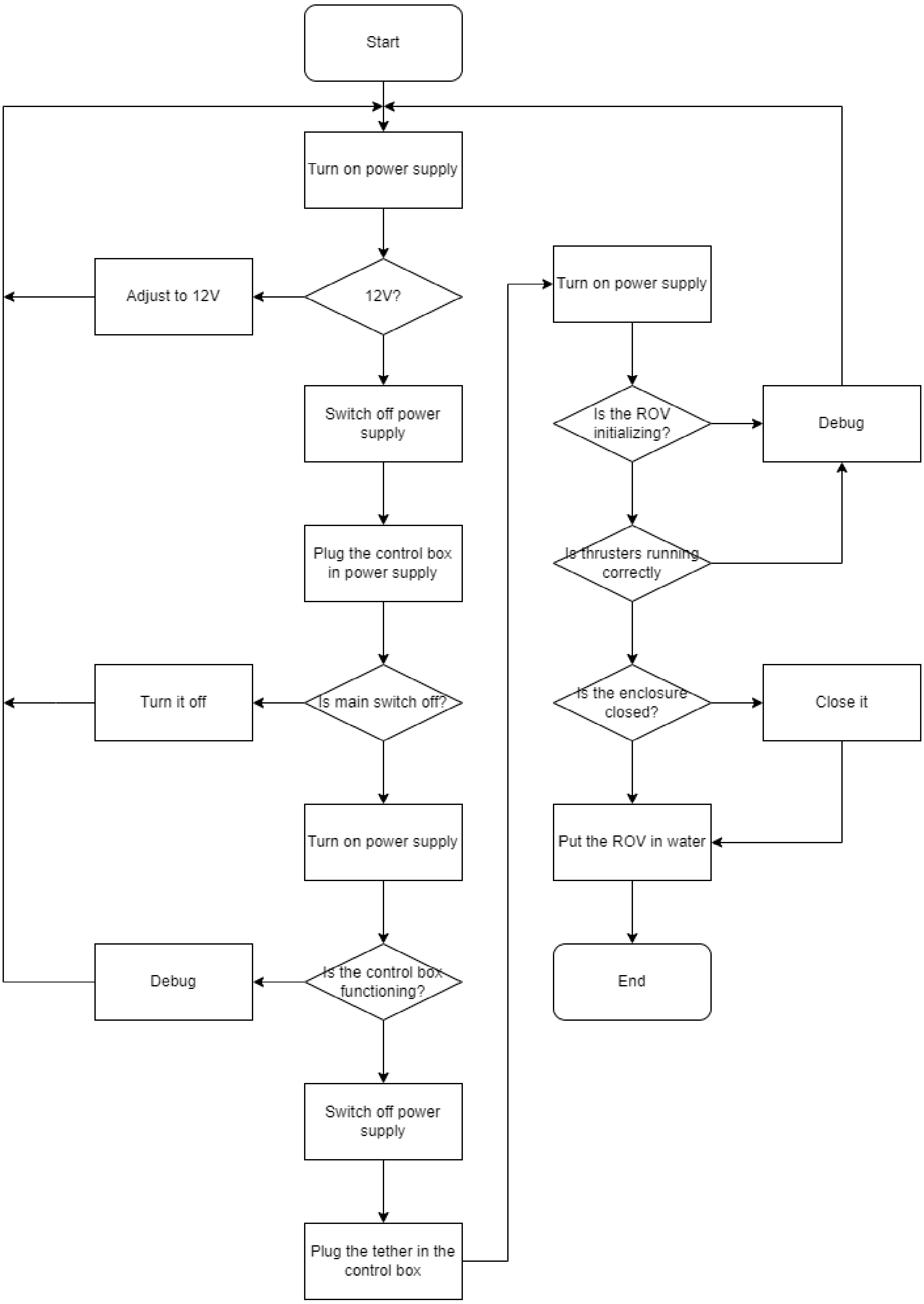


Figure 12, Guideline before piloting

7.2 Challenges and Lessons Learned

7.2.1 Technical

When we built Artemis, we faced many technical challenges. One of the challenges we faced is with the monitor in our control box. At first, the video port of the monitor was not functioning correctly. After we did some research on the internet, we found a solution.

In the beginning, when we were designing Artemis, we were very distressed because it was very difficult to design a perfect ROV. Yet, with the numerous efforts of our designers and the inspiration of the information on the Internet, we successfully designed Artemis.

7.2.2 Interpersonal

Balancing research and study at ROV can be quite a challenge for teammates, especially when it comes into conflict with tests and exams. Some teammates may feel stressed and overtired. After several attempts at dealing with the different factors that contributed to the lack of motivation, we found that encouragement among teammates was essential and most effective for our team. Create an environment of peace, joy and collaboration.

7.2.3 Future Improvements

Aquarius has already gone through many improvements and transformations and now eventually comes out with the third version. Aquarius's next step is to fortify our ROV, such as designing more tools in order to complete the task faster. Aquarius’s next step is to commercialize Artemis, by simplifying the inside structure and minimizing its weight. With the success of commercializing Artemis, the Aquarius aims at promoting ROVs to the public while arousing awareness of marine pollution.

8 References

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6. Rov maker webpage, https://www.rovmaker.com/

9 Acknowledgements

Our ROV Team would like to thanks (In no particular order):

- **SoildWorks: Thank you for offering this software.**
- **Macau Pui Ching Middle School: Thank you for the money support for building our ROV.**

Thomas Lao:
Thank you for giving us opinions, the support from the spirit, and giving up his time after school.

Chongman Leong:
Thank you for spending such a long time teaching us so many valuable techniques for us.

Our families:
Thank you for supporting, encouraging, and allowing us to study what we are doing.

10 Appendix

10.1 Budget sheet

Resource Name	Total Amount [piece(s)/bottle(s)]	Expense per one (US Dollar)	Total Expense (US Dollar)
Thruster	6	200.00	1200.00
Watertight Enclosure Tubes 4″ Series	1	216.00	216.00
Newton Subsea Gripper	1	590.00	590.00
Lumen Subsea Light	2	162.50	325.00
Bar02 Ultra High Resolution 10m Depth/Pressure Sensor	1	75.00	75.00
Watertight Enclosure End Caps and Flange Caps(4”, 14 Holes)	1	32.00	32.00
Fathom ROV Tether(25m/82ft)	1	220.00	220.00
Electronics Tray (4″ Series)	1	55.00	55.00
O-Ring Flanges	1	43.00	43.00
Spare O-Ring Se (4”)	1	3.00	3.00
Basic ESC	6	36.00	216.00
Tether Cable Thimble	1	8.00	8.00
Aluminum Assemble	4		