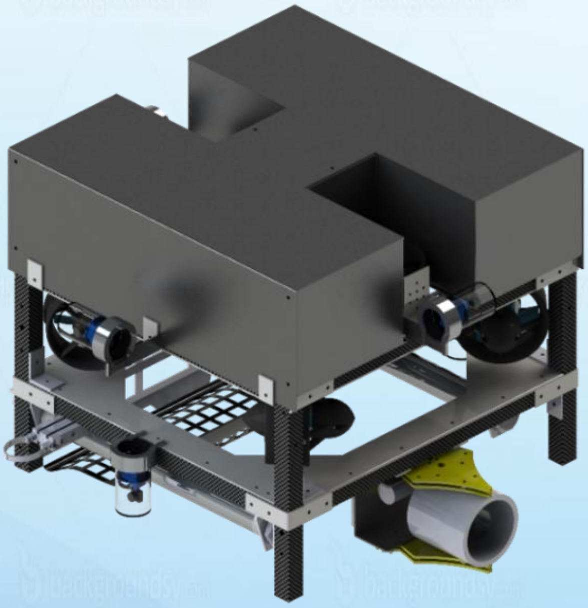
THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

Uprising
Strive for the best ROV

Upstream Salmon



Yau Geoffrey Dominic, Geoffrey — Chief Executive Officer
Lau Kam Yin, Tiger — Chief Technical Officer
Lu Yutong, Amy — Chief Financial Officer
Kuo Fei Ha, Catherine — Chief Marketing Officer
Tai Ming Ngai, Ming — Chief Procurement Officer
Wan Tak Yan, Paul — Head of Electrical Department
Tam Yee Nok, ET — Head of Mechanical Department
Yung Hoi Ki, KK — Head of Software Department
Chan Wan Yu, Jasmine — Product Manager
Wong Ching Kit, Elton — Project Manager
Shi Yunfei, Emily — Safety Manager

Cheung Hiu Fung, Dickie — Electrical Engineer
Cheung Yu Tam, Fishball — Mechanical Engineer
Lam Ho, Nicholas — Mechanical Engineer
Leung Tak Chun, Ben — Mechanical Engineer
Tang Wai Yin, Tony — Mechanical Engineer
Chan Ka Wai, Harry — Software Developer
Lee Man Kit Tommy, Tommy — Software Developer
Liu Yin Ching, Raven — Software Developer

Supervised by Dr. Steven Boles, Dr. Yu-fai FUNG, Dr. Ka-chung WONG

I. Abstract

This report describes the Upstream Salmon, an Explorer-class Remotely Operated Vehicle (ROV) that has been designed and developed as a deliverable based on specifications given by the MATE Center. The ROV can accomplish missions under unfavorable environments including the deep ocean and outer space on Jupiter's Moon Europa. This ROV is capable of demonstrating: (1) data collection and instrumentation deployment under Europa's ice sheet, (2) work in the Gulf of Mexico for critical equipment detection and recovery, (3) oil mat sample collection, (4) deep-water coral photography and collection, and (5) preparation of a wellhead for decommission and to convert it to an artificial reef.

This ROV is developed by Uprising Inc., a company devoted to develop robust solutions to real-world marine technology problems. Uprising Inc.'s mission is to construct reliable ROVs, which is custom-designed to meet specific requirements outlined by clients. Upstream Salmon takes advantage of the integration of propulsion, PID control, sensory, and vision systems. Compared to the last year's robot, the major improvements are the emphasis on form factor, and the additional features such as grippers for different missions. With advanced technologies and innovative thinking, a team of all-rounded engineers utilized their professional knowledge to deliver Upstream Salmon that can tackle practical problems from the marine workplace.

Figure 1. Company photo with our latest ROV – Upstream Salmon

Top row: Elton Wong, ET Tam, Fishball Cheung, Geoffrey Yau, Tiger Lau, Raven Liu, KK Yung, Ben Mok,Joe Lai, Ben Leung

Bottom row: Dickie Cheung, Hoho Lam, Jasmine Chan, Emily Shi, Catherine Kuo, Amy Lu, Ming Tai, Brian Leung

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II. Budget & Project Scheduling

At the initial stage of this project, a budget plan is prepared by Uprising with estimated expenses based on previous year's actual expenses. Since Uprising's income is limited, the company shall adhere to the budget expenditures. As shown in Table 1, it is the project costing report for the development of *Upstream Salmon* during 2015-2016. In total, our ROV costs HKD19,731 (USD 2,529) to build.

To complete the development of *Upstream Salmon* on time, a Gantt chart is used for scheduling generic resources as well as for project management. It illustrates the start and end of each task of this project.

Uprising Inc. 2016 Project Costing				
	Item No.	Item Name	Remark	Subtotal (HKD)
Upstream Salmon Expenses	1	Blue robotics Thruster with ESC		9180
	2	Cable (35m)		150
	3	Signal Cable(35m)	Fiber and LAN	168
	4	Carbon fiber tube (0.6m)		680
	5	Aluminum sheet		500
	6	Acrylic tube (1m)		60
	7	Buoyancy Foam		50
	8	DC/DC Converter	48/24V, 48/12V, 48/5V	690
	9	Fuse Set	MCB, Sockets, Fuse	292.5
	10	24V DC Motor with ESC		89.8
	11	Sensors	Temperature, Pressure, IMU	105.5
	12	Arduino Pro Mini		50
	13	Raspberry pi b+		220
	14	Rotatable Camera	Servo, Camera	339.6
	15	Joypad		50
	16	Epoxy		360
	17	IP68 Connectors		250
	18	Compressor with filter and regulator		700
	19	Pneumatic Parts		2520
	20	Fiber to composite		135
	21	Digital video recorder		106
	22	On shore control panel to include the complete system	Monitor, Control Box & Unit, Router	2200
	23	Clamps, Tools, Cutter		80
	24	Soldering Equipment		35
	25	Miscellaneous		720
Total Project Cost				**19731.4HKD**
				2529.67USD
The building cost is fully sponsored by PolyU Electrical Engineering department.				
Travel & Logistic Cost	**Oversea travel expenses for 17 member**			**221,000 HKD**
				28,333.33USD
Sponsorship from PolyU				**150,000 HKD**
Total Cost in USD				**30,863.00**
Balance in USD				**11,632.23**

Table 1. Total costing of Uprising Inc. for the development of Upstream Salmon in 2016

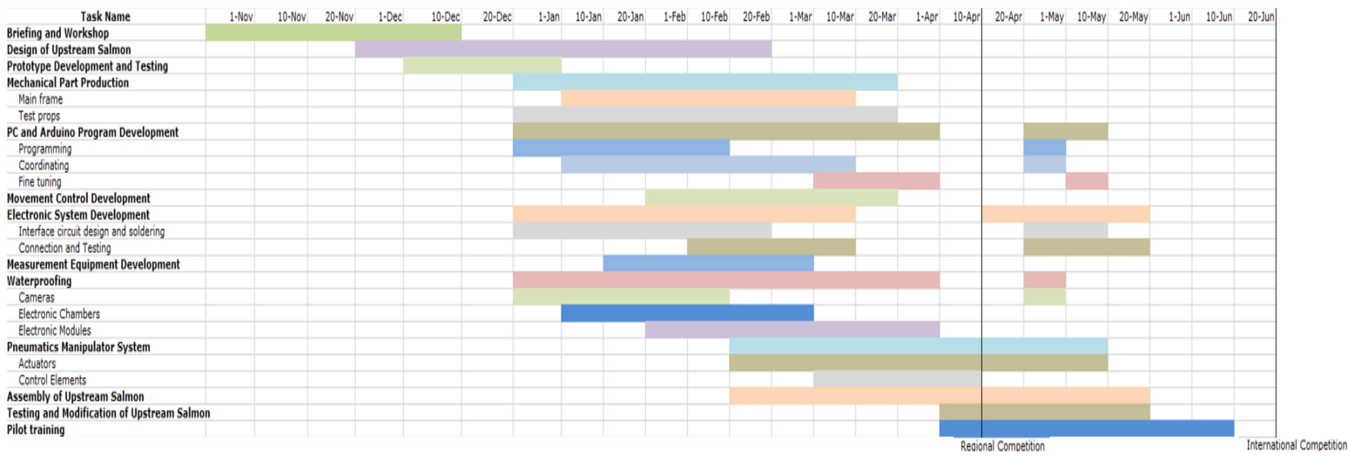

Figure 2. Uprising's Gantt chart for main tasks

III. Safety

A. Company Safety Philosophy

Safety is the first priority to Uprising Inc. and is taken very seriously during the manufacturing of *Upstream Salmon*. Numerous rigid safety protocols have been strictly implemented during different phase from designing, building, handling and testing of the *ROV.*

B. Safety Protocols

For the sake of employees' safety, our company adopts stringent safety measures. All engineers attended mandatory basic safety training offered by the Industrial Center of The Hong Kong Polytechnic University and got the safety card. Safety checklist from MATE is also strictly followed by the engineers. Appropriate safety equipment, such as safety goggles, ear protection and safety shoes, are required when dealing with power tools. Masks and gloves are always worn when handling hazardous chemicals, like epoxy.

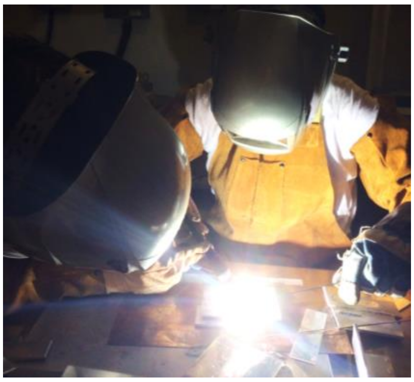

Figure 3. Welding workshop in the Industrial Centre at PolyU

C. Upstream Salmon's Safety Features

Upstream Salmon contains many safety features to keep our personnel, the ROV and the working environment safe and healthy. For electrical and electronic divisions, motor shrouds are used to cover thrusters. Fuses are installed in live wires and no Tee-joint is allowed ahead of a fuse. Various waterproofing techniques are applied to make sure no water leakage so that the electrical system remains dry. During Construction, the crew is aware of the presence of sharp corners at all times.

D. Safety Checklist

Operational safety protocols are dictated by a safety checklist in terms of pre-power, on-power, ROV retrieval and leak detection protocol. The safety Checklist is attached in the appendix.

IV. System Integration Diagrams

A. Electrical & Electronic System Integration Diagram

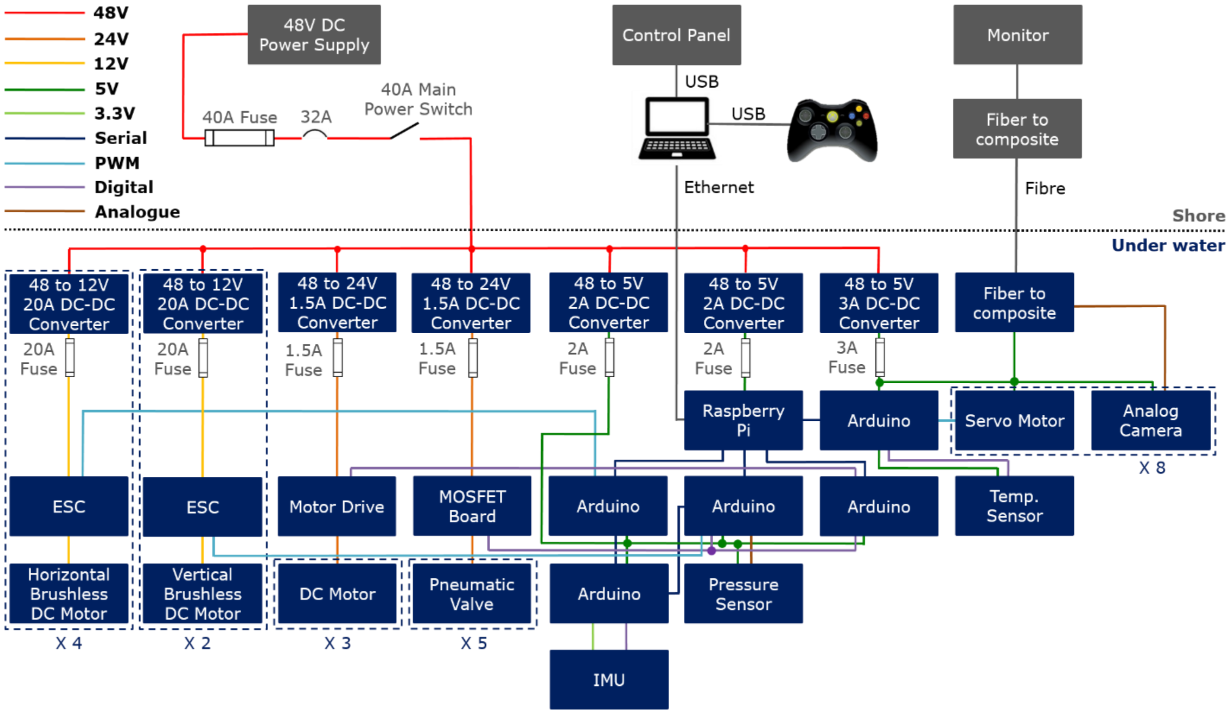

Figure 4. Electrical & Electronic System Integration Diagram

B. Pneumatic System Integration Diagram

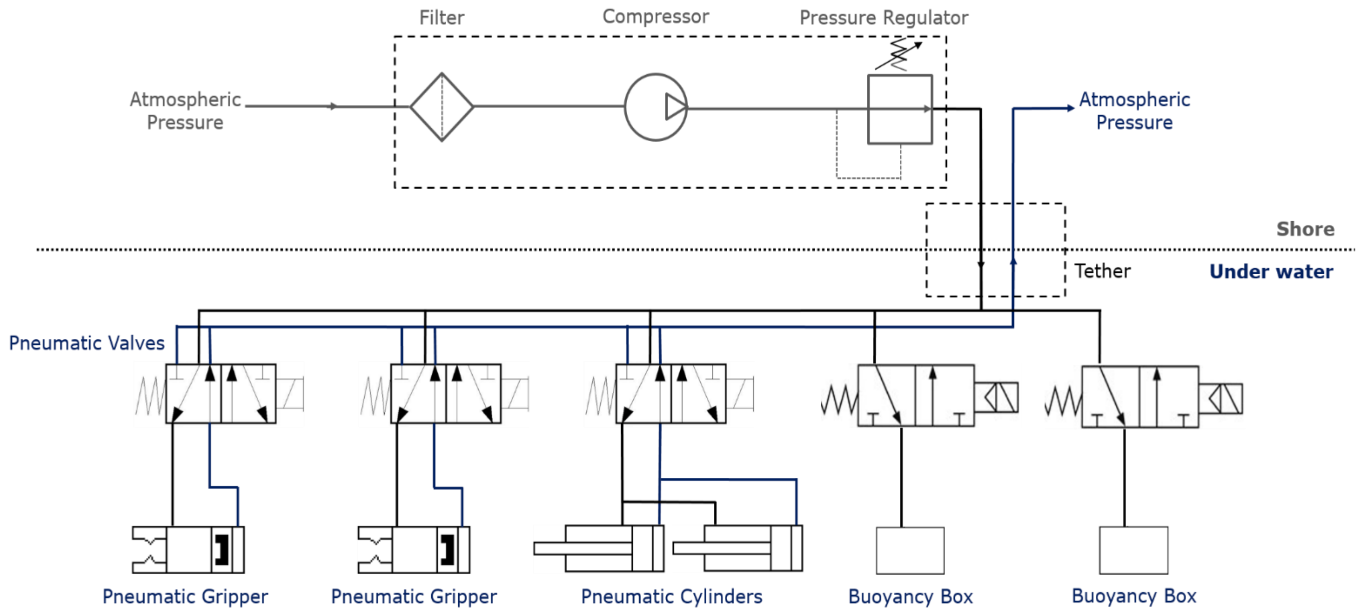

Figure 5. Pneumatic System Integration Diagram

V. Design Rationale

After meetings and brainstorming, employees exchange their voices. Seniors have shared their experience from previous competition which is applied on the Upstream Salmon design and drafted as fig. 6. From idea to draft, decisions are made under careful consideration regarding shape, size and material selected, keeping functionality as well as cost effectiveness.

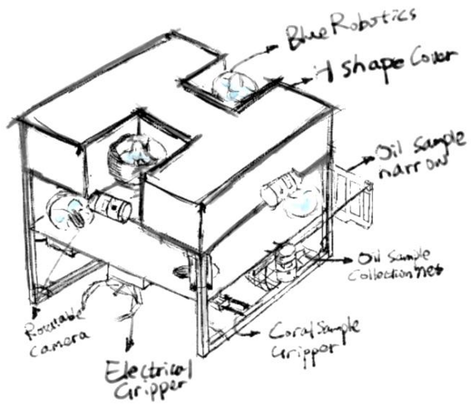

Figure 6. Draft illustration

A. Mechanical Design

1. Frames

In order to link all main parts together in a rigid structure with a lightweight and a brilliant appearance, carbon fiber tubes and aluminum sheets are used to construct the joints and the skeleton.

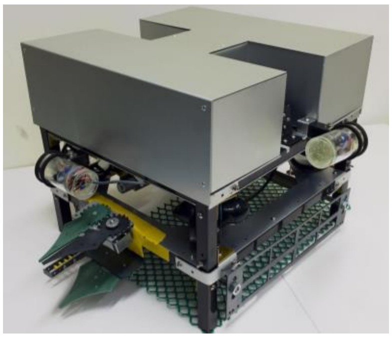

Figure 7. Upstream Salmon Frame

Carbon fiber is a composite material which is formed with the plastic resin (matrix) and woven carbon filaments resulting in a high strength-to-weight ratio material. Lighter material is favorable in the ROV for larger buoyancy with the same volume, and material with higher strength can withstand higher mechanical loading. Thus, a square carbon fiber frame is used to support the aluminum sheet where the other components are mounted with screws. In addition, the hollow carbon fiber tube is chosen because it will allow for applied external stress before failing according to the equation 1:

$$\delta_{max} = \frac{qL^4}{8EI} \qquad eq.(1)$$

where δ is the max deformation due to stress, L is length of the object, E is the Young's modulus and I is the moment of inertia of the object.

The larger the moment of inertia, the less the deformation there will be. As the hollow tube has a greater moment of inertia than the solid one, the hollow tube may produce less deflection under stress. Therefore, a hollow square carbon fiber tube is selected.

Aluminum is a strong and oxidation resistant metal, and has a high strength-to-weight ratio. After anodization, the oxidation resistance is even better. Aluminum sheet is easy to be formed as any flat pattern by punching (fabricating process), so it suits various designs well. As the strength of the Aluminum increases after bending process, aluminum sheet metal is used to make the joints.

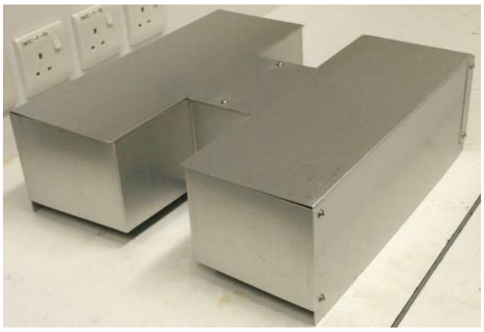

Figure 8. H-shaped cover

2. Propulsion System

Four motors are used to control the transitional and rotational motion of the ROV. Not only does the motor mounting pattern shown in Fig. 9 distribute the propulsion force of four motors, but it also maximizes the force as well as the torque of the ROV and eliminate the turbulence. Assuming the magnitude of the four forces produced by the rotation of blades are identical:

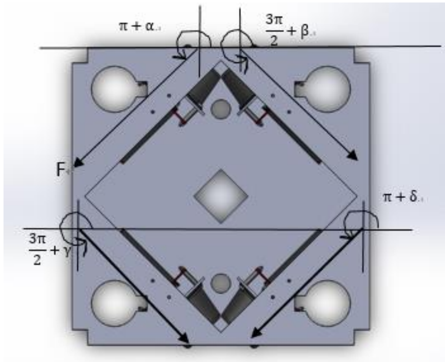

Figure 9. Motor Mounting

$\alpha = \beta = \gamma = \delta = \theta$

$$F_{net} = \mathrm{F} \cdot \sin(\pi + \alpha) + \mathrm{F} \cdot \sin\left(\frac{3\pi}{2} + \beta\right) + \mathrm{F} \cdot \sin\left(\frac{3\pi}{2} + \gamma\right) + \mathrm{F} \cdot \sin(\pi + \delta)$$

$$\frac{\mathrm{d}F_{net}}{\mathrm{d}\theta} = -\mathrm{F} \cdot \cos(\theta) + \mathrm{F} \cdot \sin(\theta) + \mathrm{F} \cdot \sin(\theta) - \mathrm{F} \cdot \cos(\theta) \qquad eq.(2)$$

For the maximum force produced,

$$\frac{\mathrm{d}F_{net}}{\mathrm{d}\theta} = 0$$

$$\sin(\theta) = \cos(\theta) \;\Rightarrow\; \theta = \frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}, \dots\dots. \qquad eq.(3)$$

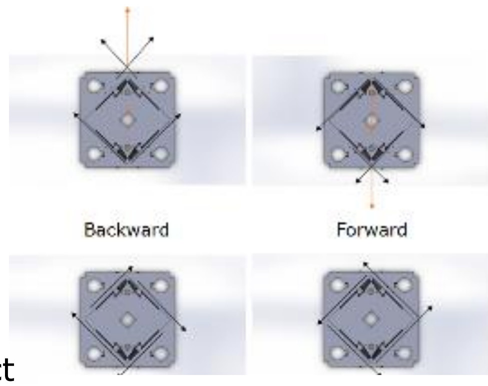

Figure 10. Patterns of four motor mounts for controlling transitional and rotational motions

From eq. (3), when θ=45°, the brushless direct current motor (BLDC) gives a maximum force and torque on the ROV. The direction control of the ROV can be achieved by applying force as shown in Fig. 10.

B. Waterproof Mechanism

1. Waterproof Methods

Method 1: Waterproofing with an acrylic chamber

Upstream Salmon is equipped with acrylic tubes which are sealed with epoxy. Acrylic is for its high transparency (about 92%) and hardness. Also, acrylic is accessible and easy to be processed. 3mm-thick acrylic is selected to make the chamber to ensure the components work properly 30m under water. Also, to avoid air condensation inside the tubes, the size of the chamber is reduced and an anti-fog layer is coated inside the chamber.

Method 2: Waterproofing with Polyepoxide[1]

All of the electronic components of *Upstream Salmon* are modularized with polyepoxide in a 3D printed container that is specially designed for mounting on the frame. A heat sink is added to components of which the dry test temperature is over 40°C to cool down the modules. Waterproof connectors are used to connect electronic components and they could be replaced of electronic components.

The type of polyepoxide selected for modularizing the components of *Upstream salmon* has low viscosity. The chosen polyepoxide is corrosion resistant, excellent heat conductor, electric insulator and has compressive strength. Polyepoxide as transparent material is favorable for monitoring the working performance of the electronics by adding LED light signals.

Method 3: Waterproofing with silicon oil

Motion units like the motor gearbox are filled with silicon oil to prevent water flooding and failure, and the oil filling hole is sealed with bolt and O-ring. Silicon oil is selected among numerous materials because it is colorless, odorless, hydrophobic, electrical insulator and good heat conductor. Although paraffin oil has the above properties, it is highly flammable and toxic, and therefore not selected because of safety concerns.

Testing on polyepoxide modulation

Uprising has conducted a series of waterproofing test for the epoxy modularized component. It aimed to test whether the thinnest part of epoxy would be cracked or deformed under high water pressure. The test was conducted under

Figure 11. Epoxy module with cobalt chloride paper

different water pressures. The result in table 2 shows that modularized components can withstand under 17.5 psi, which is the required depth for the MATE competition. It also reveals that all modularized components could withstand at least 72psi pressure, which is four time higher than the requirement.

Pressure(Psi)	17.5	30	43	58	72
Result	pass	pass	pass	pass	pass

Table 2. Pressure Testing on Epoxy Module

2. Comparison and Application of Waterproof Methods

Table 3. Comparison of waterproof methods

Method	1	2	3
Flexibility	**	*	***
Reliability	*****	***	****
Size	***	*****	*****
Weight	**	****	***
Production cost	***	*****	*****
Time cost	***	*****	****
Maintenance cost	***	***	***
Environment concern	****	*****	*****
Overall rating	*****	****	*****

Remark: * refers to the efficiency level (1. Acrylic chamber 2. Polyepoxide 3. Silicon oil)

Method	1	2	3
Electrical components		✓	
Valve		✓	
Motor	✓		✓
Thruster		✓	✓
ESC	✓		
Camera	✓		

Table 4. Application of waterproof methods

Sealing with polyepoxide is the most suitable method for mounting electrical components and pneumatic valves into a stable position. Boxes are used to protect each DC motor by the same sealing method, and is attached to the gear box which is filled with silicon oil. Motion units that cannot be modularized, such as motors and thrusters, are filled with silicon oil to provide viscosity for the gear to move smoothly underwater. ESC (Electronic Speed Control) for the thrusters and cameras that require high transparency for imaging and monitoring ROV's status are waterproofed by acrylic chambers.

C. Manipulator Design

In order to execute tasks defined by MATE, different types of manipulators were designed and tested.

1. Pneumatic Manipulator

Upstream Salmon has implemented a pneumatic system designed specifically for coral samples and oil samples collection. The system incorporated two pneumatic cylinders to collect oil samples, two pneumatic grippers to retrieve coral samples, and two buoyancy boxes to attain auto-buoyancy.

To collect coral samples, the selected double acting pneumatic gripper is installed such that its end-effector moves horizontally. This configuration optimizes the holding force required to lift the coral samples by trapping the coral in the gripper instead of by friction, thus smaller sized grippers can be chosen to utilize space effectively.

The single-rod double acting pneumatic cylinders are designated to collect oil samples from the oil mat. The ends of the cylinder rods are attached to the claw which is used to pull oil samples into the collection net on the return stroke. This configuration reduces the cylinders' occupied area. The cylinder is chosen to have half length of the ROV so that some space can be spared for other components to mount on the other end. The cylinders chosen have a bore size of 25mm and a stroke length of 250mm.

Figure 12. Adapted claw's design

Figure 13. First claw's design

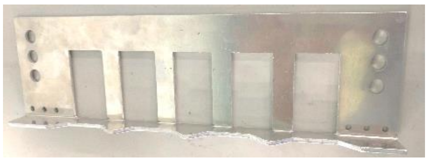

Figure 14. Second claw's design

The claw, as shown in Fig. 12-14, is made up of 2mm sheet metal with holes to reduce water drag and consequently enhance the actuation speed of the cylinders. Three claw designs were constructed. After testing the claw in Fig. 12 is adapted in the final product as this design is the most effective approach on collecting oil samples.

2. Electric Manipulator

To convert electrical energy into mechanical energy, the characteristics of BLDC, DC and AC motors were investigated. BLDC motor has better starting torque, peak efficiency and a simpler driving controlling system. The comparison in table 5 is based on the results from researching and controlling test. Also, pressure test and condition test were conducted for the waterproofing performance.

Table 5. Comparison of different motors

Performance	BLDC Motor	DC Motor	AC Motor
Starting Torque	***	***	**
Peak Efficiency	***	**	*
Control System	**	*****	*
Waterproofing	****	***	**

A comprehensive design can fulfill the torque-speed requirement, including high torque-low speed and constant power-high speed region. In our ROV, high-torque low-speed is the most suitable for the manipulator's motion. So, a gearbox with suitable ratio can basically simplify all mechanisms and provides the most reliable movement.

ESP Collector

The collector of ESP connector is constructed from a waterproofed dc motor that gives a torque of about 23 kg/cm for turning motion. The flexibility of the collector can be increased by adding motors on the corresponding positions as its degree of freedom increases. This would satisfy different requests from the pilot by achieving a low cost tailor-made manipulator.

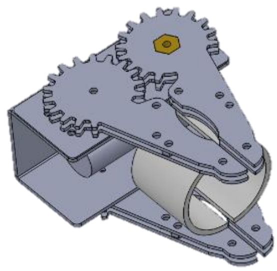

Figure 15. CAD model of electrical ESP collector

Electrical Gripper

Electrical gripper demonstrated another design from the same type of motor. It aims at universal uses for multi-tasking purpose, such as Rigs to Reefs, sample collection or even provides the underwater cleaning service. Similar to the ESP collector, this gripper can easily increase the degrees of freedom and hence provide a higher flexibility for different uses.

Figure 16. Electrical gripper

D. Electrical & Electronic System

1. Power & Peripheral Control

In the electrical power system, DC-DC converters are used to supply power with different voltage levels to different devices. In order to minimize the energy loss during voltage conversion, two main strategies are applied: reducing the number of voltage levels and using converters with higher efficiency. In order to reduce the number of voltage levels in the system, devices operating only at 24V, 12V and 5V were selected. Converters with higher current rating can be utilized to power more equipment. Not only the cost but also the energy loss in voltage conversion can be reduced. For the second strategy, DC-DC converters with efficiency over 90% were chosen, eliminating the heat generated and the effect brought to the environment.

For the sake of accomplishing the missions, actuators are essential. Both pneumatic and electric actuators are chosen to accomplish different tasks. Due to the different voltage levels and poor driving capacity of Arduino, MOSFET and H-bridge are needed. For pneumatic system, valves are driven by MOSFETs. Using MOSFET as switch is a simple, reliable and efficient method.

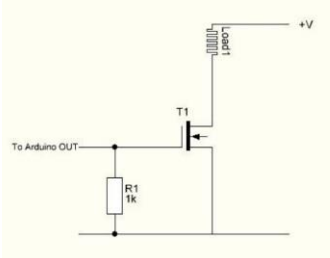

Figure 17. Circuit of MOSFET

For electric actuators, H-bridge is used to control the DC motors. The H-bridge IC chosen is L298n, which is a TTL logic level H-bridge IC with an input voltage up to 46V. Rotating direction and speed of DC motors can be driven easily with this IC.

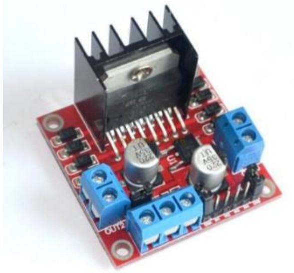
Figure 18. L298n H-bridge IC

2. Vision System

Upstream Salmon is equipped with a well-designed vision system for navigation purpose. Seven rotatable cameras and one fixed camera are used to provide a 360°view around the ROV as well as fulfill specific mission requirements, and the signal is transmitted through an optical fiber to the on-shore monitor.

The previous generation of *Upstream Salmon* employed IP camera and web camera, yet the latency of the digital system (IP camera system) increased the operational difficulty. According to Hill et al. [2], latency can be reduced to less than 60ms in a pure analogue system, and is less than 50% of the latency in a digital system (640X480 with 80% quality).To minimize the latency, analog cameras are applied in this year.

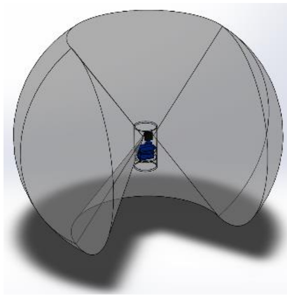
Figure 19. Rotatable Camera View Angle

The rotatable camera is manufactured by mounting a 140° wide-angle analog camera on a 180° servo hosted inside a 70mm acrylic tube. It provides a 270° view underwater. With the rotatable camera, the number of cameras reduces from 23 to 8 providing the same total view angle.

Signals from the cameras are transmitted through a 35m-single mode optical fiber, which is selected mainly to reduce the electromagnetic interference and increase the carrying capacity of the cable. The previous digital system encountered significant noise (electromagnetic interference), and resulted in system failure due to overload. However, since the optical fiber transmits the signal as light instead of current, the interference problem is solved and the system becomes more reliable. Moreover, thinner and more flexible, the optical fiber transmits the signal (1.25Gbps) with weight reducing from 20kg/km comparing to that of a LAN cable 5kg/km. The degradation of the signal can be reduced to less than 0.32dB/km [3]. As a nonconductive cable, optical fiber facilitates the waterproofing process. It is also worth noting that the pin to pin time delay (t_{PD1}) of the optical transceiver module is around 5 ns which is negligible, and therefore, the system of analog cameras together with optical fiber performs well with acceptable latency.

Mission-Specific Camera Layout

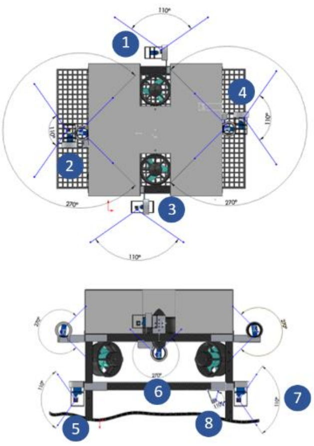

Figure 20. Camera Layout

- Four rotatable cameras on top (①②③④) are used for monitoring the surrounding and capturing the coral colony in the task4.
- Two cameras at the bottom (⑤⑦) provide the 360° view to support different mission tools such as ESP collector, electric gripper, harrow and temperature sensor.
- The center bottom camera (⑥) provides accurate location information of the ROV to increase the descending velocity and accuracy.
- The fixed camera (⑧) with high resolution is placed near the harrow for viewing the serial number of the cube set clearer.

3. Control Panel

With additional functions to be performed, the control systems of Upstream Salmon has become more complex than our previous gamepad version that cannot fulfill the current control requirements. Hence Uprising has implemented a new design of control system by combining a 430 x 300 mm control panel with a 19” monitor inside a safety equipment box. The modified design of the control box increases the portability of the whole work station.

Figure 21. Control box

A video splitter is installed inside the control panel so that 4 out of 8 camera views can be displayed at the same time for navigation and mission accomplishment purpose.

Also, the enlarged space of the control system allows more than one operators to control devices (tuning the video, controlling the manipulators) on drive the ROV simultaneously. The panel is designed to provide control for the cameras, manipulators and the lighting. The switches produce different signals which are connected to an Arduino processor. The Arduino processor is connected to the notebook computer which is responsible to send the proper control to the ROV.

4. Sensory System

The ROV is required to collect the temperature and depth data under water. To detect the temperature of water, DS18B20 is used for the required temperature range and accuracy (0.0625°C resolution). The depth is calculated with corresponding pressure. MPX4250DP (pressure sensor) which gives a large measurement range (up to 25m depth) to meet the requirement is applied. After the ROV measurement test, the sensors are found to be ±0.5°C accuracy from -10°C to +85°C and 25m with ±10 cm error (after adopted Kalman filter[4]) respectively. The turbulence this sensors suit the requirement by MATE.

Figure 22. Pressure sensor

Figure 23. Temperature sensor

E. PID Control System

In order to improve the stability of the ROV, a PID system is implemented. This can help the ROV pilot to achieve the tasks such as installing the ESP in a shorter time.

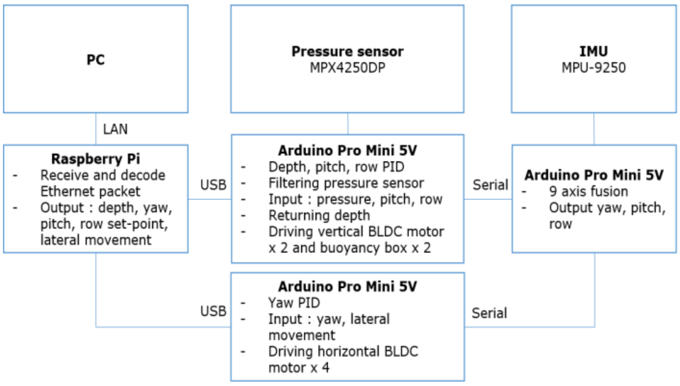

Figure 25. Overview of the PID Control System

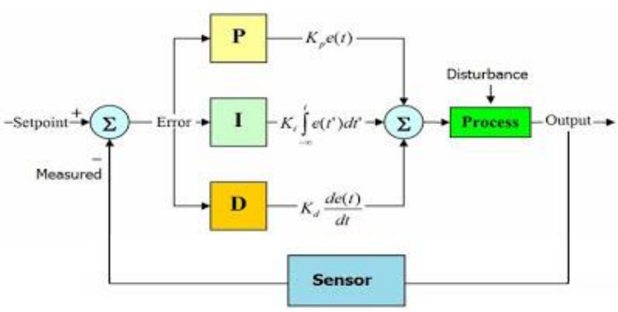

Figure 24. Block diagram of a PID controller in a feedback

In our ROV, the process corrected by this PID controller is the motion of the ROV including moving horizontally and vertically. However, there are various kinds of disturbances under water which makes the output of the process differ from the desired one. Therefore, in order to measure how much the real output is different from the desired one, sensors are essential to measure the actual output of the process.

From the above figures, there are four PID controllers in our ROV correcting four motion-related parameters, namely, yaw, pitch, roll angles and depth. Yaw, pitch and roll angles are the orientation of the ROV. These angles are calculated from the orientation quaternion computed by the onboard Digital Motion Processor™ (DMP™) inside the MPU-9250 9-axis inertia measurement unit (IMU) from InvenSense at a rate of 200 Hz. The calculations are shown below.

$$\vec{q} = [q_0\ q_1\ q_2\ q_3]^T \qquad \text{, where } \vec{q} \textit{ is the orientation quaternion}$$

$$\begin{bmatrix} Roll \\ Pitch \\ Yaw \end{bmatrix} = \begin{bmatrix} atan2(2(q_0q_1 + q_2q_3), 1 - 2(q_1^2 + q_2^2)) \\ \sin^{-1}(2(q_0q_2 - q_3q_1)) \\ atan2(2(q_0q_3 + q_1q_2), 1 - 2(q_2^2 + q_3^2)) \end{bmatrix} \qquad eq. (5)$$

Depth is another parameter that is corrected by the PID controller. In our ROV, pressure sensor MPX4250DP has a maximum error of 3.45 kPa which is equal to an error in water depth of around 35 cm. Also, even if the sensor is confined in a static environment, the measurement reading is still fluctuating. These errors will affect the performance of the ROV when it is supposed to maintain a fixed depth of submerging. Therefore, Kalman filter is adopted to optimize the performance of the sensor.

Kalman filtering is an algorithm that estimates unknown variables. This process tends to be more precise than those based on a single measurement alone. As shown in the figure. 26, the algorithm involves 2 steps which are prediction step and update step. The filter can be complicated if several dimensions and different sensor data are combined. However, in our ROV, only one dimension is enough and no multiple sensors are needed. Therefore, among all variants of Kalman filter, the simplest one is chosen so as to save processing power.

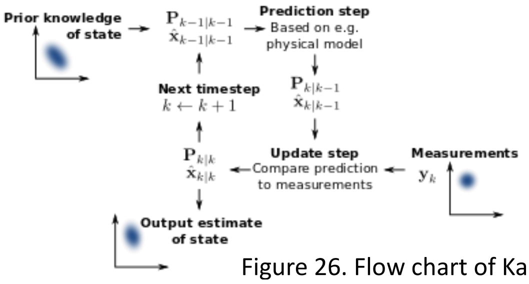

Figure 26. Flow chart of Kalman filter

Prediction step : $p = p + q$

Update step : $k = \dfrac{p}{p + r}$

$$p = (1 - k) \times p$$

$$x_k = k \times (x_{k-1} - x_k) + x_k \qquad eq. (6)$$

With Kalman filter and DMP, noises in sensory data are minimized. Thus, our PID controller is implemented to correct the motion and buoyancy of the ROV.

1. Motion Control

In our ROV, four horizontal BLDC motors are responsible for lateral movement as well as yaw angle control, and two vertical BLDC motors are used for water depth control and roll angle adjustment. As accurate yaw, roll angles and water depth are measured, the PID controllers can calculate corresponding error in different controllers. With the help of proportional, integral and derivative control, different set-points can be achieved. The ROV can maintain fixed yaw, roll angles and water depth even if it is moving laterally.

Figure 27. T200 Thruster from Blue Robotics

2. Buoyancy Control

In order to adjust the buoyancy and the pitch angle of the ROV, two acrylic buoyancy boxes are installed at two sides of the ROV. The ROV is required to pick up several items in different missions, such as coral samples, oil samples and ESP connector. The weight of these of items will affect the center of gravity (C.G.) and the buoyancy of the ROV when they are picked. Changing the C.G. will alter the pitch and roll angles. The two buoyancy boxes are responsible for correcting the pitch angle while the two vertical BLDC motors would react to the roll angle change. The buoyancy and the pitch angle of the ROV can be easily modified by the boxes through injecting air inside the box. There would be small holes on the boxes for air to escape slowly.

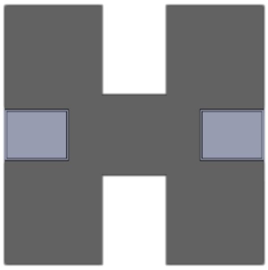

Figure 28. Acrylic buoyancy box location

F. System Software

The system software is running in different devices both onshore and onboard the ROV. The major computing devices onshore are the notebook computer and an Arduino. Onboard the ROV, there is a Raspberry PI, and multiple Arduino processors.

1. Onshore

Figure 30. Control description of Xbox gamepad

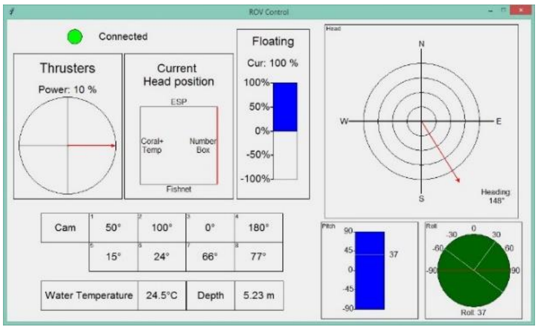

Figure 29. Working state of GUI

The onshore system includes a notebook computer which provides the link via a LAN cable to the ROV. Control signals generated by the onshore control panel are sent via the notebook to the ROV. Most importantly, through the software running in the notebook, the ROV pilot can control the thrusters and monitor status of the ROV.

The control software on notebook computer is developed using the *Python 3.4* programming language. The notebook program acts as a center of the whole control system to give commands to the ROV, receive data from the ROV, collect input from the user through the Xbox controller and control panel, and display the status of the ROV on a GUI. The Xbox controller is responsible for all the movements of *Upstream Salmon*, while the control panel provides a simple interface for the pilot to control other sub-systems, such as lighting, buoyancy and manipulator. The *Python* program analyzes and encodes the commands, and communicates with the Raspberry Pi 2 in the ROV through Ethernet by socket. The Raspberry then decodes and issue commands to different Arduino sub-systems in the ROV accordingly by serial port. The directions and output power of thrusters can be adjusted by using the Xbox controller to carry out different movements of the ROV, like moving forward or backward, shifting left or right, and rotating clockwise or anticlockwise.

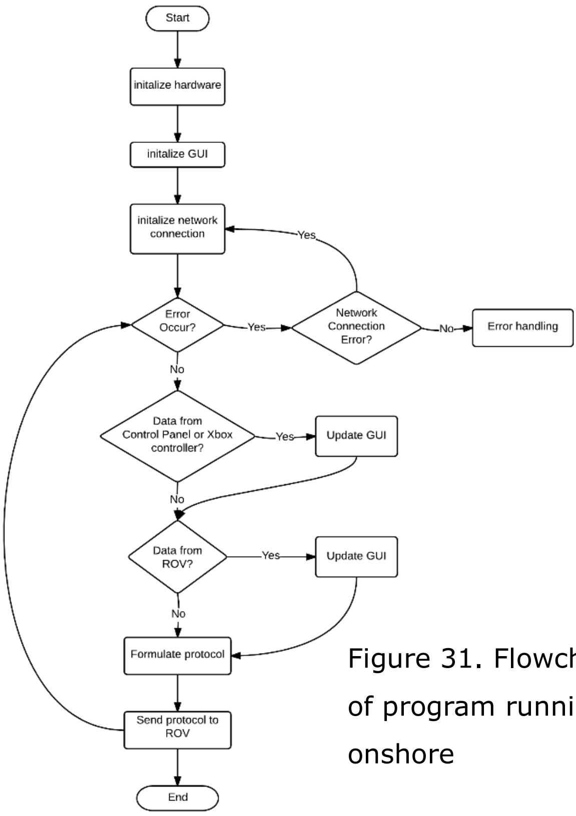

Figure 31. Flowchart of program running onshore

2. ROV

In the previous design, Arduino Mega is used as the core and performed badly on network congestion that increased the delay. The limited processing power (16MHz) and memory space (256KB) of Arduino Mega make it not capable enough to handle the communication with the sub-systems. Therefore, Raspberry Pi Model B+ is chosen as the core of the ROV as it is running an Linux operating system, i.e. more capable to handle network congestion, and the processing power (800MHz) and memory space (512MB) of it is enough to handle all sub-systems.

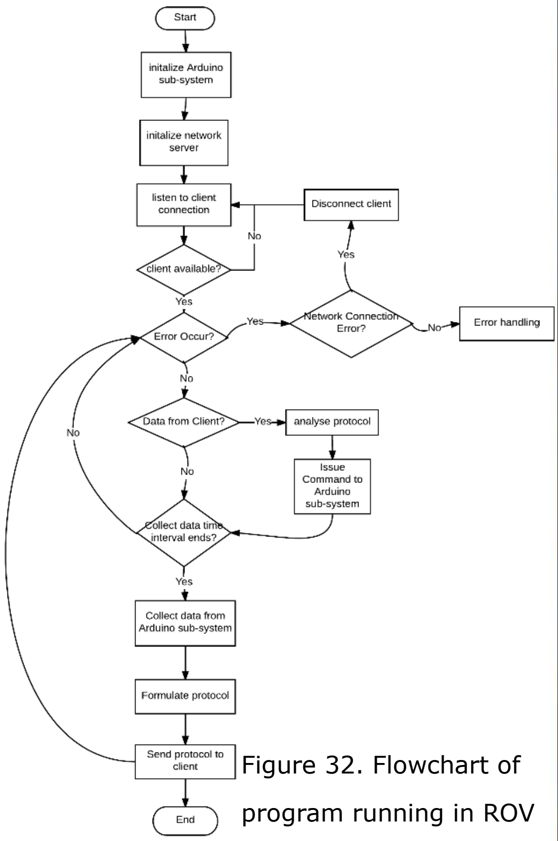

Figure 32. Flowchart of program running in ROV

Ethernet is used as the communication channel between the ROV system and devices on shore. An Ethernet cable is connected between the Pi and the notebook computer on shore. And the Pi is connected to another Arduino sub-system by USB serial communication. Thanks to the use of Raspberry Pi, instant maintenance onshore is possible by SSH to the Pi, even maintaining the Arduino sub-system without a computer.

G. Troubleshooting Techniques

The crew tested different waterproofing methods. The initial version of the chamber is made up of acrylic plates, epoxy, bolts and rubber gasket. By using a compressor chamber, the water pressure was increased to 28 psi which equivalent to 20 meter depth. The test result revealed that the plastic chamber with 2mm wall failed to withstand the water pressure due to the joint cracked at the water pressure of 14 psi.

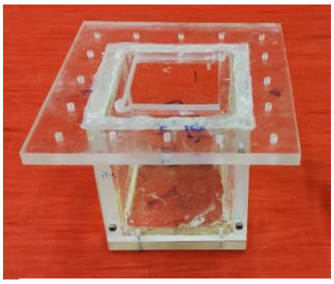

Figure 33. The initial chamber

A modified sample of the waterproof box was then constructed by aluminum plates welded together. A box cover with a rubber gasket was bolted to the plate. The test showed that this modified chamber could withstand a water pressure of 42 psi (28m depth). However, air inside the chamber was condensed when the chamber is cooling by the water. High humidity would shorten the lifetime of electric components. The waterproof chamber was tightened with 40 bolts which would consume over an hour to open and close for system checking.

Since epoxy modularized components have a higher stacking efficiency than the waterproof chamber, the components can be mounted on the frame easily. They can be packed in multi-layers without getting electric modules overheat since polyepoxide used has a higher thermal conductivity than water. It provides a better cooling effect to the electronic modules. All the components sealed with polyepoxide were tested to be operating under 44psi over an hour without getting overheat or other failures.

VI. Conclusion

A. Challenge

1. Technical challenge

To build the *Upstream Salmon*, the first challenge is the waterproofing techniques that should be adopted. Although the ROV could perform well on shore, it may fail to complete tasks underwater. In the absence of an appropriate waterproofing method, the electronics would be destroyed and causing the ROV unable to carry out tasks.

To ensure the reliability of Upstream Salmon, a pressurized chamber is made to simulate the deep water conditions. The pressurized chamber is constructed by an aluminum box, rubber gasket and a cover, can compress the water pressure to 43 psi (about 30 m depth) for testing. With this compression chamber, the waterproofing ability of interconnectors, cameras and motors can be verified.

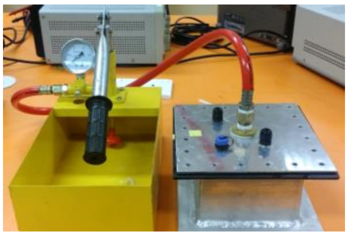

Figure 34. Pressurized chamber

Another difficulty is dealing with the straight requirements for the dimensions and weight of the ROV this year. To tackle this problem, the ROV model is built in software and the size of the ROV can be well kept inside a 40cm square. However, the weight control is much more difficult than the volume control. Uprising needs to take a balance between buoyancy and weight after the size control. Therefore, the density became the major consideration for the selection of materials used. Proper materials should be chosen in order to maintain the above-mentioned balancing and to reduce the burden of the propulsion system.

2. Non-technical challenge

Two major non-technical challenges are highlighted during competition. Tightening schedule, with plenty of work needed to be completed within months, is one of them. The local competition date is held in April which is on the examination period, and our employees were, at the same time, facing final examinations and preparing the final stage of competition. In the face of huge workload, Uprising had a well-planned division of work in accordance with the expertise of groupmates. The crew put on consistently distinguished performance and displayed conscientiousness and diligence in performing tasks.

Another challenge is to take demonstration video for the qualification requirement. Besides the tight schedule of team members, the school swimming pool was only lent for an hour in two weekdays. Such opening schedule is unflavored, in which teammates must set up the workstation fast and troubleshooting time is hardly provided. Not to mention it takes several approaches to obtain a satisfactory clip. To fight for the opportunity, all our teammates work their hardest to contact suitable venue and borrow equipment.

B. Lessons Learned

1. Technical

Due to different functional, interdependent departments in a large-scale company, Uprising faced a lot of technical challenges. At the beginning of this project, it was found that a systematic arrangement of all resources is essential, but difficult. Hence the crew has made good use of additional technical organizational tools, like Gantt chart, Git for source code management, and Google Drive for all important documents and photo galleries. Moreover, there are some technical matters in the movement parts, including cameras, the robotic arm and propulsion system of *Upstream Salmon*, which had never been encountered. Only when the crews inspire their ideas and share experience with each other, will the challenges become our stepping stone and improve our techniques.

2. Interpersonal

Under high demand and heavy workload, the crew has gained experience in self-management and self-initiative with our determination. In response to the crowded and compressed schedule, Uprising Inc. has created division of work with a to-do list showing the tasks that each employee should be responsible for. Employees who finished their own work efficiently could enjoy the rest of their time or contribute to the accomplishment of others' work. Uprising Inc. has run in an effective and efficient manner in a way to secure the development process of *Upstream Salmon* with full participation.

Teamwork and team collaboration have long been the significant factors in all group-based contests. Before joining Uprising, some employees are not acquainted with each other because of different disciplines and different study years. By the shared experience and expertise to achieve the same goal – developing the best *Upstream Salmon* ever, our team worked together week by week, through which our teammates acquire strong bonding in the team. It is learned that communication is always needed when different parts of work are ready for integration, and this naturally led to new friendships.

C. Future Improvements

The first generation of Upstream Salmon has two chambers to evenly distribute the floating force so the center of gravity could be kept. The second generation has it's center of gravity adjusted with two vertical thrusters. Until now, we have adopted a PID system to maintain the stability and to control the buoyancy of the ROV. In PID system, some power is used to stabilize the ship, which limit the use of propulsion power. It would be the best to attain neutral buoyancy by the ship mass itself to improve the power efficiency.

In previous year, the weight of the ROV appeared to cause transportation problem in both lifting and shipping. Although the weight has greatly reduced in this year design, it is still not in a convenient weight for people to carry on road or to operate. Frame and mount composite a majority part where weight could be cut. Selecting the correct materials and designing a structure with minimal screws and bolts. Tenon could be used to build a strong joint and rigid structure.

D. Reflections

1. Senior member Reflection

"Joining the MATE competition last year left me with many new ideas and unfulfilled goals that made me want to participate once again. This year I have set myself new goals which would grow on a team level for the upcoming MATE competition. Being a senior member, I have been challenged to guide a group of teammates by developing a timeline and delegating individual work to them. It was

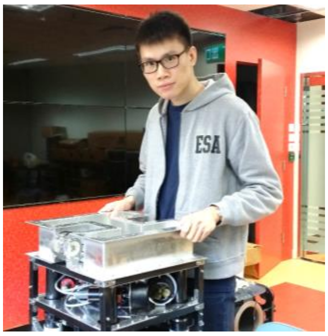

Figure 35. Tiger Lau

really an enjoyable time in spending all the sleepless nights filled with both stress and laughter. Working with PolyU ROV Team has definitely added a different flavor to my university life and given me an unforgettable experience worth cherishing."

- Tiger Lau, Chief Technical Officer

2. Junior member Reflection

"Joining Uprising Inc. as a year 2 student in 2015 has given me a general idea of the underwater robotic field. I found it hard to understand the discussion in the first group meeting, but the seniors unreservedly passed their technical know-how on to me so that I could learn different technical skills fast and get involved in camera system group. Participating in the system design and do soldering as well as troubleshooting provides me with precious hands on experience. The team morale is great that time goes fast when we work together."

Figure 36. Emily Shi

- Emily Shi, Electrical Engineer

E. Corporate Social Responsibility

Uprising Inc. helped coordinating ROV workshops to help local and international participants foster and develop skill sets and knowledge to build their ROV's. Also, Uprising Inc. joined "Maker Faire Hong Kong 2015", in which participants can learn how to control the ROV to perform basic operations underwater. We conducted a workshop on "Building an underwater robot" in April. The workshop is one of the HK SciFest 2016 program organized by the Science Museum of Hong Kong, the workshop is intended to elevate the public's interest in science and technology especially related to underwater remotely operated vehicle (ROV). Moreover, we are pleased to support, Kwok Tak Seng Catholic Secondary School (KTSCSS), a ranger-class team for MATE competition, for giving them advice and assistance in building their ROV.

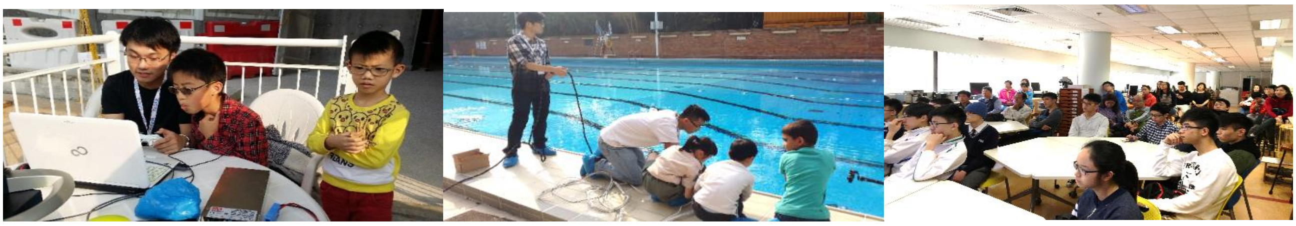

Figure 37. Maker faire and ROV workshop

VII. Reference

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VIII. Acknowledgements

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MATE Hong Kong
The Institution of Engineering and Technology, Hong Kong
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Figure 38. Logos of the acknowledged parties

IX. Appendix

A. Safety Checklist

Personal:

Shorts or skirts are not allowed in the pool area

Shoes must be covered with a shoe protector

Safety goggles must be worn at all times if power tools are used at the workbench. No power tools on the pool deck

Logistic:

When transporting the ROV, watch out passengers, and the ROV should not bump into other equipment.

Do not be tripped by tethers.

Handle the Equipment gently.

Pre-Power:

Area clear (no sundries in the way)

Make sure that the power switches and the control panel are in off mode.

Make sure that fuses or circuit breaker are connected properly

Make sure no bare wire exposed

All devices are properly secured

Make sure that tether is properly secured and is properly connected to the Control box and Robots

Make sure that there is no obstruction in thrusters

Ensure that all waterproof connections are connected tightly

Adjust the pressure to be regulated under 40 psi

Power-up:

Ensure that the voltage supply is 48V

Control computers up

Ensure team members are not touching the voltage line

Inform team mates that the power will be on

Power on and perform thruster test and buoyancy test

Verify the status of cameras and arms

Test temperature sensors and pressure sensors

Launch:

Captain shouts out: “Ready to launch”

Team members beside the pool are well prepared

All crew members shout: “Launch!”

2 students squat down to launch the ROV, 1 student holds the cables

Make sure that students do not twist their waists

ROV Retrieval:

Captain calls out: “Ready to retrieve!”

All crew members retrieve the ROV on the periphery of the pool

Turn off the thrusters

Turn off the power supply to the control box

Emergency:

If pressure lines are loose from the valves, retrieve the ROV and reconnect all the pressure lines

If the arm stops working, retrieve the ROV and change the spare servo motors

If the camera system loses communication with the computer onshore, check all the connection status of the related cables