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THE HONG KONG  
UNIVERSITY OF SCIENCE  
AND TECHNOLOGY



# Technical Report

MATE 2016

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Hong Kong

# Abstract



Figure 1 Computer Aided Design of the Orca

This technical documentation elaborates on choices made by Epoxsea Inc. during the development of the Orca as the Remotely Operated Underwater Vehicle (ROV) that resolves request for proposal issued by Marine Advanced Technology Education Center, NASA Johnson Space Center's Neutral Buoyancy Lab, and Oceanering Space System (OSS). The request is to construct an ROV that can be deployed in the ocean of Jupiter's moon, Europa, for scientific purposes, and also in the depths of the Gulf of Mexico for offshore drilling and retrieval missions. Considering the desired functions and applications, it is critical that the ROV should have minimal size and weight while maintaining functionality to reduce expense on transportation and maintenance.

There are some major changes implemented in the Orca's design if juxtaposed to the ROVs produced by Epoxsea Inc. in previous years. Instances of those major changes are removal of the electronics tube from the ROV, change of type and number of thrusters, and switch of framework material from aluminum to polyethylene. These changes will be justified and illustrated through the conceptualization of the Orca's design, and how a series of decisions was executed such that the concept was able to be realized. During development of the Orca, challenges were faced, but there were also valuable lessons learned. All in all, these changes and challenges were faced and overcome in order to make the Orca the best means of completing the designated tasks on Earth and Europa.



Figure 2 Epoxsea 2016 Team Photo

Top row (left to right): Gaurav Vijai Jeandani, Tang Can-Yao, Ngai Cheung, Xinjie Yao, Hans Ryan Tanubrata, Mang Tik Chiu, Yau Pun Chen  
Bottom row (left to right): Randitya Setyawan Mohamad, Richard Lawrence, Christian Edwin Pranata, Gian Miguel Del Mundo, Cheng-Hsin Wu, Albert Tanoto, Hongseo Yoon

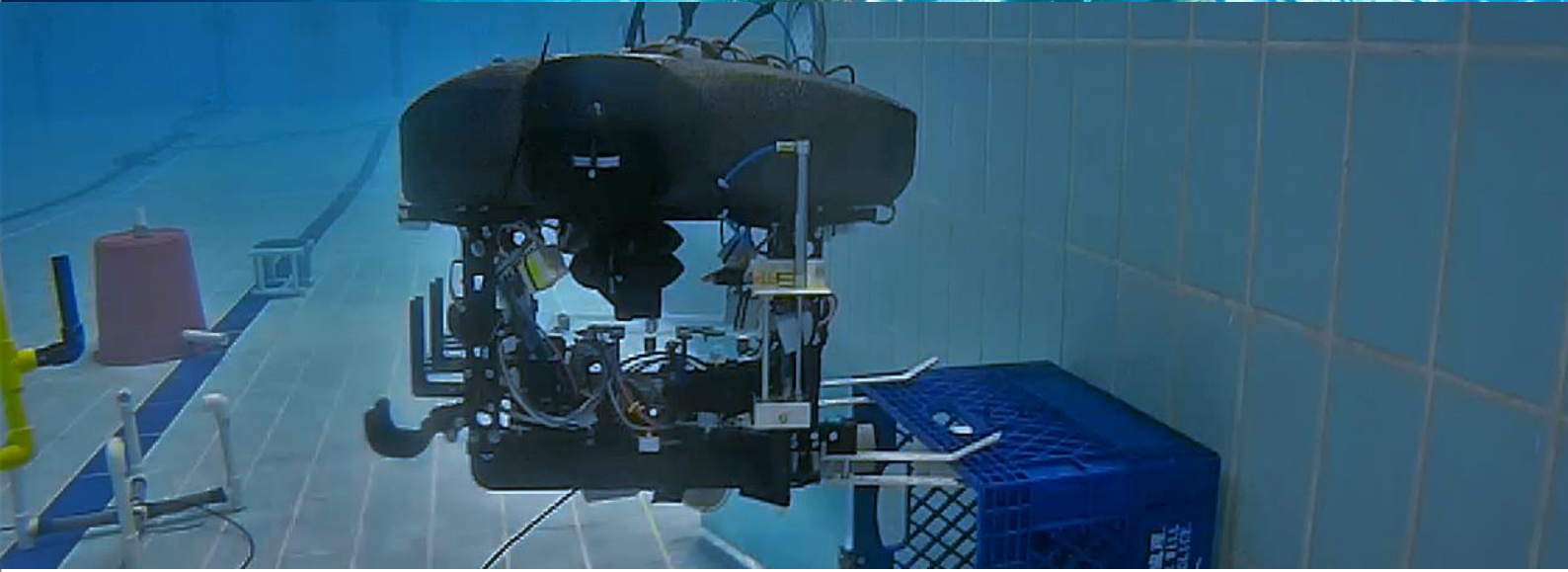


Figure 3 The Orca attempting to insert the Environmental Sample Processor (ESP) cable connector to the power and communication hub

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# Design Rationale

This year, a request was made for an ROV that is able to aid observations and operations under great depths of oceans on Jupiter's moon Europa and Gulf of Mexico. This means, in addition to functionality, said ROV must have minimal size and weight to economically deliver it to Europa. In response to this request, Epoxsea Inc. has designed, developed, and realized the Orca, which features simplicity, lightweight design, small physique, and great range of functionality. By removing the bulkiness and weightiness from the Orca, it becomes suitable for intercontinental and interplanetary transport, and apt for easy dispatch to one's desired location.

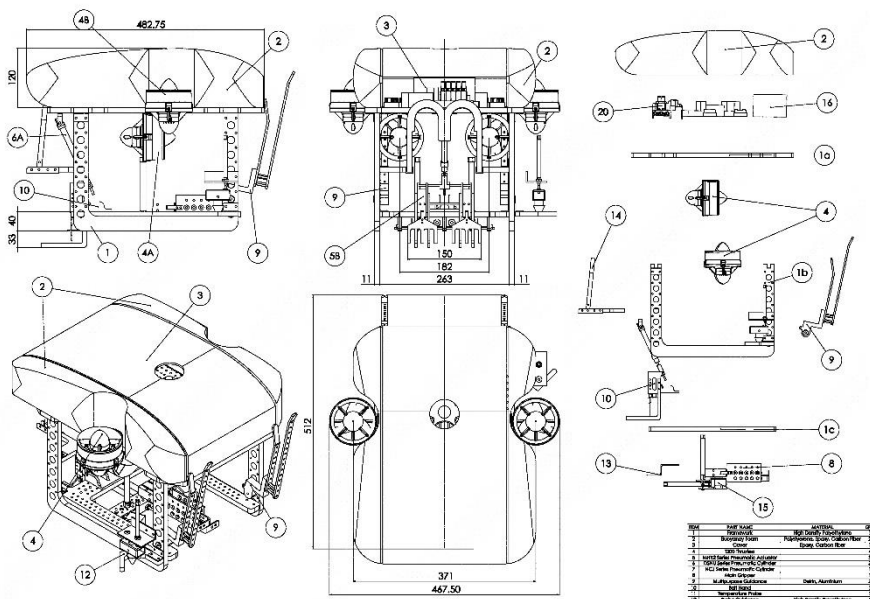


Figure 4 The Orca engineering drawing  
Dimension: Length x Width x Height (0.51m x 0.47m x 0.40 m)  
Mass in air (11.50 kg)

# Design Evolution

From year to year, Epoxsea Inc. has strived towards improving our product in terms of functionality, performance, and aesthetics. This year, Epoxsea Inc. developed the Orca, a powerful, yet the smallest ROV so far. Compared to its predecessor Stingray (Epoxsea Inc. 2015 ROV), the Orca is 54% smaller by size and 53% lighter by weight. The minimal size and weight of the Orca was achieved due to changes and improvements made in the mechanical design and electronic components. For instance, instead of using 6061 anodized aluminum alloy as the base material for the framework like in the previous ROVs developed by Epoxsea Inc., the Orca uses High Density Polyethylene (HDPE) instead. This significantly reduces the overall weight of the machine without compromising on the integrity of the framework. Also, unlike previous Epoxsea Inc.'s ROVs, the Orca does not use an electronics tube as the housing for electronic components to conserve space. As a substitute, each electronic component (e.g. regulators, motor drivers, camera board) has its own 3D-printed housing that is waterproofed using epoxy. These components are then positioned near and around the centralized main board on the top side of the Orca's body. The chosen waterproofing and positioning method of the electronic components eliminates the concern of water leakage, a concern that would arise when using electronics tube, and hence improves durability. Removing the electronics tube also cuts out an intermediary, thus allowing the shore to directly communicate with the microcontrollers, and vice versa, and increasing the speed of maintenance, especially when debugging the components (compared to experience from previous years).

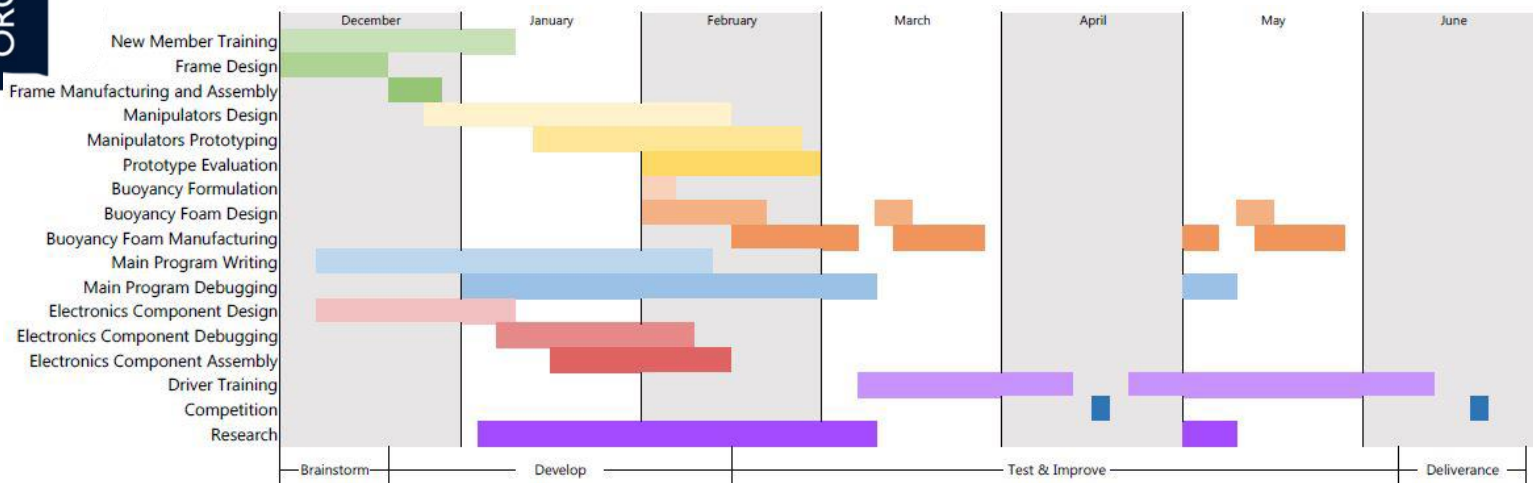


Figure 5 Build schedule of the Orca

# System Interconnection Diagrams

The electronics system integration diagram designed by *Yau Pun Chen* featuring all of the connections from the shore to the Orca and the pneumatic system interconnection diagram elaborating on the connections present between valves in the Orca are shown below.

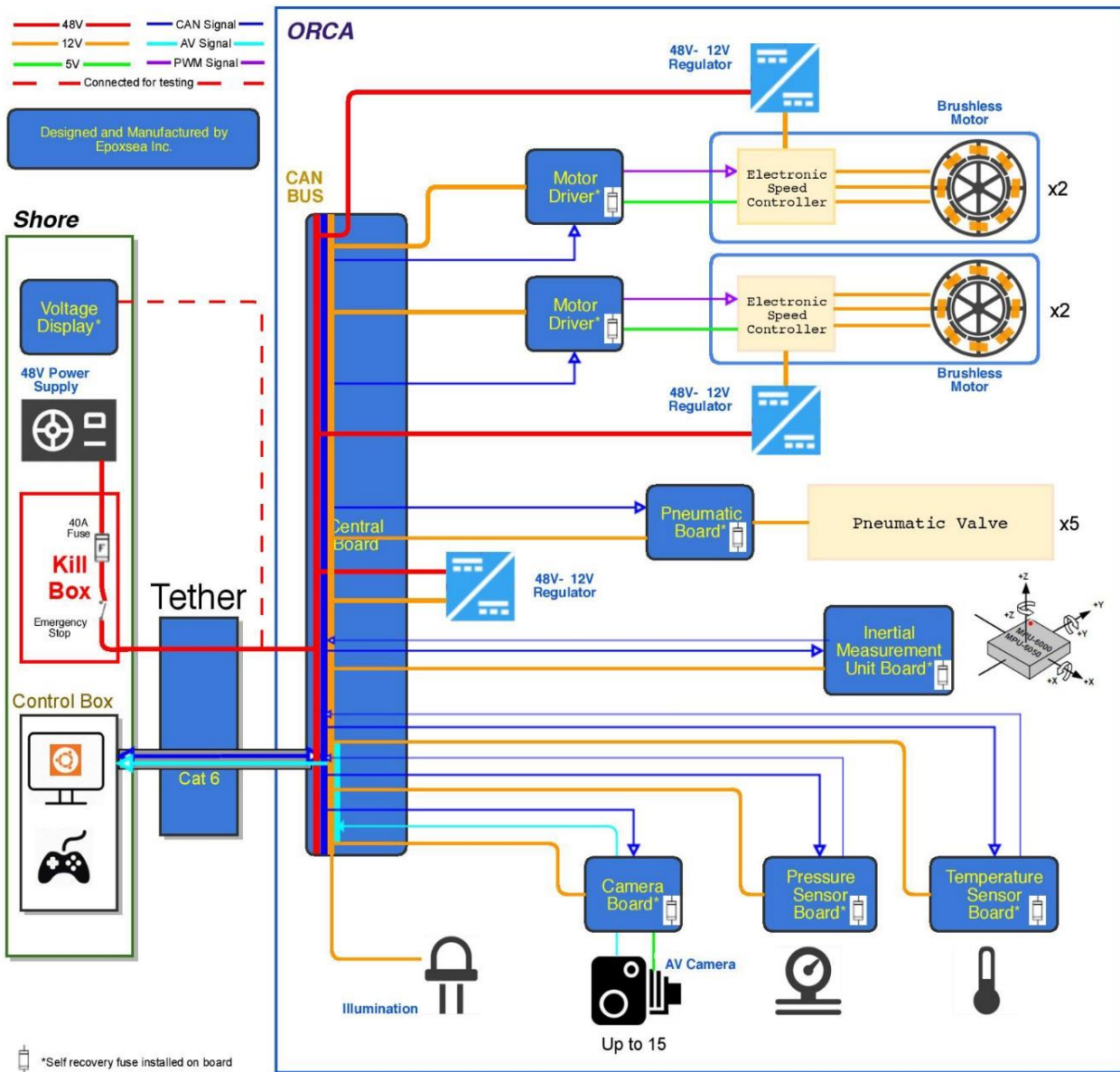


Figure 6 Electronic System Interconnection Diagram

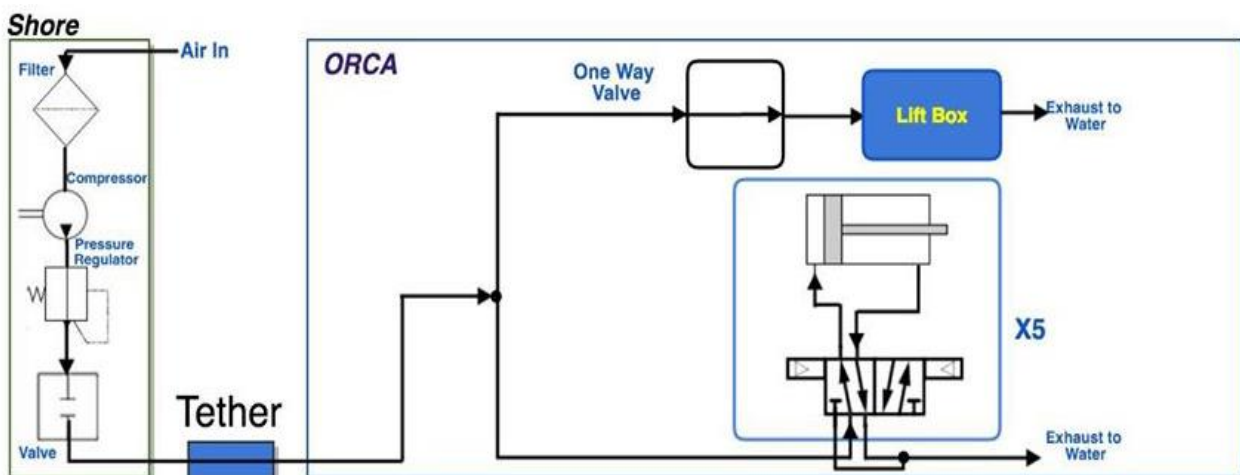


Figure 7 Pneumatic System Interconnection Diagram

# Vehicle Core System

## Mechanical

### Framework

With our aim of having a lightweight and minimal size ROV this year, we decided to move on from using anodized aluminum, the base material Epoxsea Inc. has been using in previous ROVs, to High Density Polyethylene (HDPE). Even though the aluminum alloy used previously was light, rigid and durable, HDPE offers similar properties with the inclusion of being lighter and corrosion resistant.

In order to ensure that the reductions in size and weight did not affect the overall functionality and performance during the missions, the frame, developed by *Christian Edwin Pranata*, adopts a 4:3 ratio, which emphasizes on length rather than width as length can help reduce drag and provide stability while the Orca is in surge as explained in [1].

The frame also adopts a two-tier design where the top half is dedicated for all the electronic components and the bottom half is dedicated towards the manipulators. With all the electronics placed on the top of the Orca, it enables us to shield our electronic components and cables underneath the buoyancy foam.

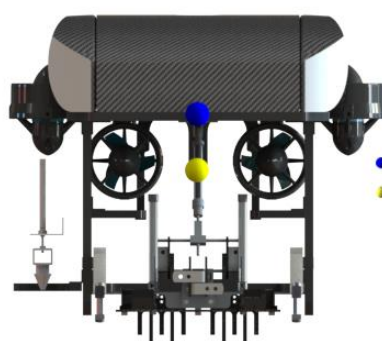
The ROV includes abundant mounting options which suits modular system components given an electronics tube is not present on the Orca. The holes of sizes M4 and M5 on the top and bottom layer of the Orca were premeditated to provide more flexibility when it came to mounting all of the electronic components and specific holes like the thruster mounts and the pneumatic manifold at the back of the Orca's frame. Once the design was finalized, it was sent to a manufacturer to be milled and drilled into the desired shape through a Computerized Numerical Control (CNC) machine to ensure high accuracy and a good level of finish.



	HDPE	Aluminium
Density ( $\text{kg m}^{-3}$ )	960	2700
Corrosion Resistance*	A	B

\*resistance grade to salt water; A - very good, B - good, C - bad, D - very bad

Figure 8 Orca's HDPE Framework  
(information retrieved from: <http://www-mdp.eng.cam.ac.uk/web/library/enginfo/cueddatabooks/materials.pdf>)



● Center of Buoyancy  
● Center of Gravity

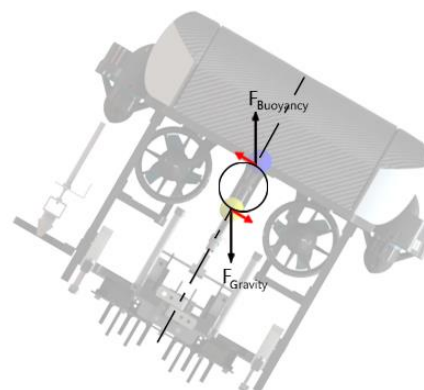


Figure 9 The Orca's design stabilization; upright position (left) and position correction after rolling (right)

Another important criterion for the framework design is stability, which is determined by the ROV's center of gravity and center of buoyancy. Stability, in this case, is the ability of ROV to return to its upright position (Figure 9, left side) after pitching or rolling. This ability is determined by the righting moment, which is proportional to the distance between the two centers (i.e. size of the circle Figure 9, right side). Due to this concept, the Orca's framework has a top tier for buoyancy foam and bottom tier for the manipulators, so that the center of buoyancy and center of gravity are as far apart as possible. In addition to this, giving space between the tiers also allows more flexibility in variation of type of manipulators that can be used, and allows less obstruction to the thrusters' flow.

## Buoyancy System

With successful results from last year's custom buoyancy foam, such as its function of providing buoyancy and its sleek design, Epoxsea Inc. decided to continue designing and engineer custom foam in-house to keep the Orca neutrally buoyant. The shape of the Styrofoam was originally designed and modeled in Solidworks by *Richard Lawrence*, allowing the most hydrodynamic shape to be developed such that drag is reduced and performance is improved.

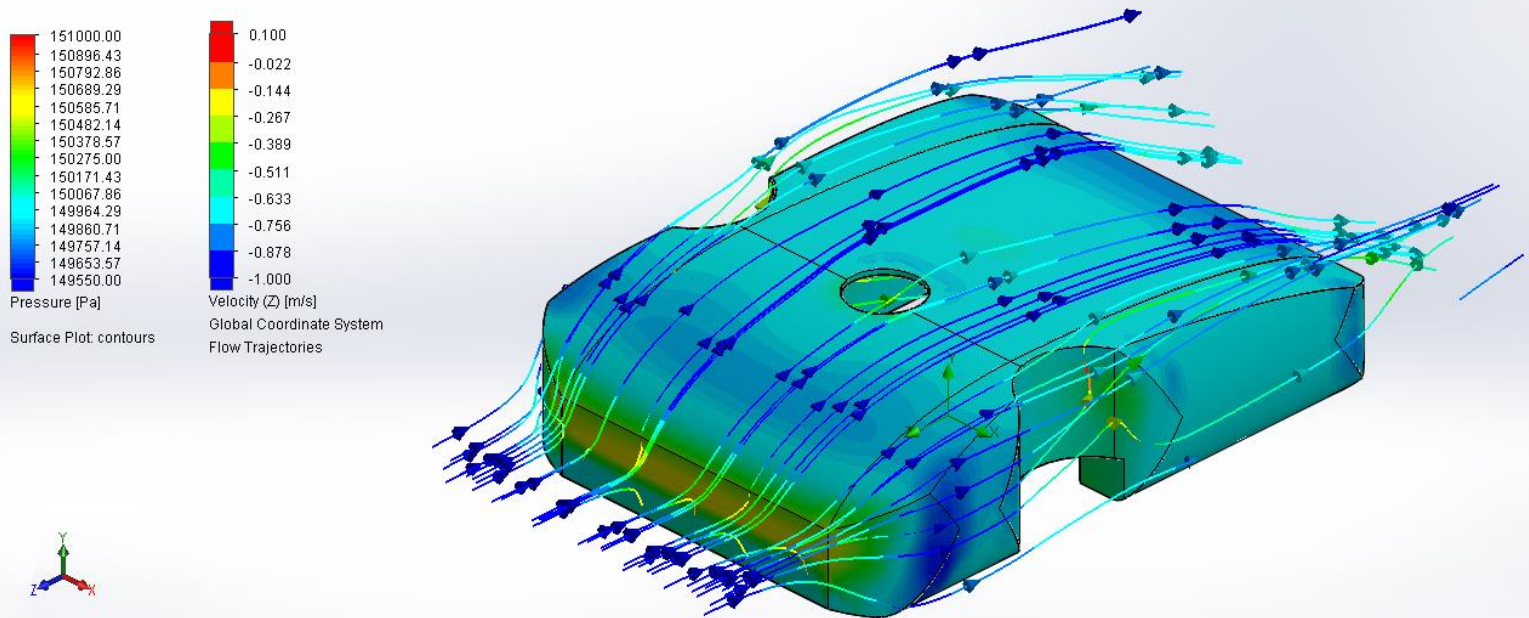


Figure 10 SOLIDWORKS Flow Simulation on Orca's buoyancy

After being shaped, it was covered with two layers of epoxy followed by three layers of carbon fiber to fix the low points and prevent deformation respectively as the Orca descends underwater. In addition, the Orca features a new form of adjustable buoyancy to cope with additional weight added when lifting the CubeSats in mission-critical equipment recovery task. The foam is designed in such a way that exhaust air from the manipulators can exit out of the Orca's body through the "blowhole", which basically is a hole located on the ROV; this blowhole is located on the maximum point of the buoyancy foam, which allows air bubbles from the exhaust to exit through it instead of accumulating inside, mimicking an Orca's blowhole.

In order to stabilize the Orca during recovery of mission critical equipment, a Lift Box is installed to act as a counter-balance when it is tilted and as a means to provide an extra buoyancy when needed. The Lift Box is made of a bottomless rectangular acrylic box. It uses air from the compressor, supplied by a manifold, where the pressure of the air will push out the water and thus increasing volume of the Orca. In order to prevent the water from getting into the manifold, a single way valve is used to control the flow direction of the air and the water. Moreover, by adding a flow regulator, we are not only able to control the flow speed of the air but also keep the pneumatic system more stable.

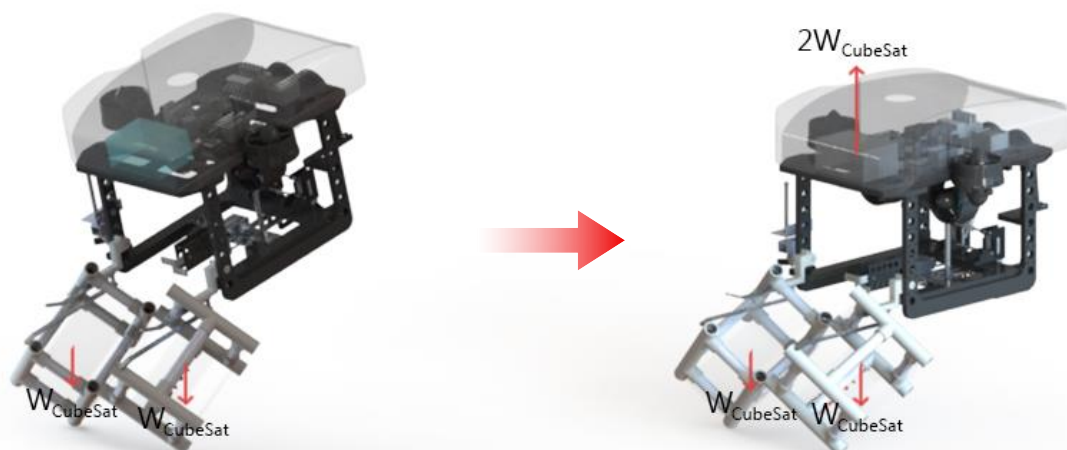
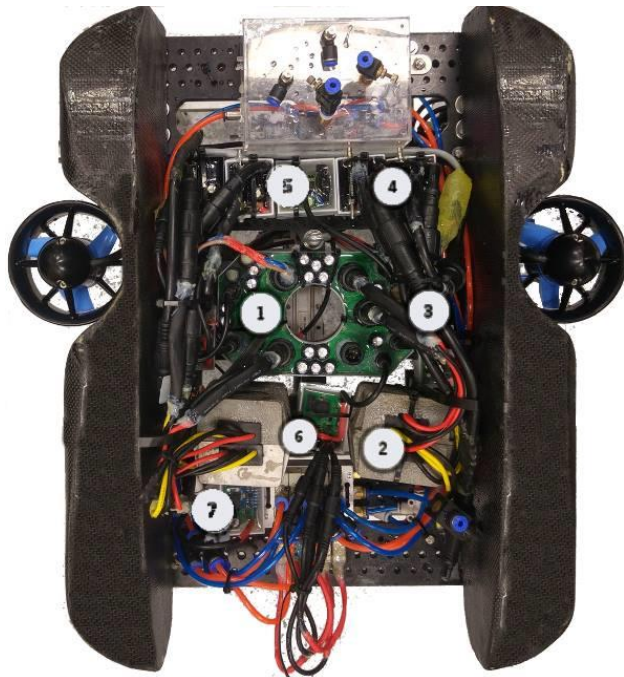


Figure 11 Lift Box when not activated (left) and activated (right)

# Electronics



## Electronics Components

- 1 CAN Bus + Power Board
- 2 48-12 V Regulator
- 3 Motor Driver Board
- 4 Electronic Speed Controller
- 5 Pressure Sensor
- 6 Pneumatic Board
- 7 IMU Board
- 8 Camera Board
- 9 Temperature Sensor

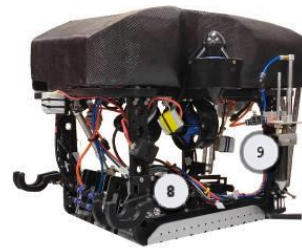


Figure 12 A top (left) and side (right) view of the placement of electronic components on the Orca

## STM32F103

All the electronic boards in the Orca are controlled by several STM32F103 microcontroller units (MCU), which include a camera board, a pneumatic board, two motor drivers, an inertial measurement unit device, a pressure sensor and a temperature sensor as shown in the System Interconnection Diagram (Figure 6). Besides being cheaper, this specific MCU was chosen by Epoxsea Inc. as it offers many high level features in comparison with other MCUs. Although it does not provide as much processing power as some more advanced STM32 class MCU, it provides sufficient peripherals and efficient speed and performance for use in the Orca. This in turn allows the MCU to be made as small as possible and modular which is aligned with the Orca's overall design approach; minimum size and maximum functionality.

## CAN Bus Framework

The high baud rate that the Controller Area Network (CAN) Bus offers (up to 1.25 Mbps) and its capability in reducing noise has been proven reliable and substantial in last year's Stingray. For this reason, the Orca inherits the same architecture as a communication system. The CAN signal is transmitted from the shore to control a set of MCUs that will execute various functions, such as adjusting motor thrust, controlling pneumatics, switching between cameras and reading sensor data.

## Power Board

In order to achieve a minimalistic design and allow for the best possible cable management in the Orca, the method of implementation of the power input and CAN was re-designed. The two systems were integrated together on a single circuit board. The integration and placement of this board in the center of the ROV allows for easy access to all of the power and CAN signal ports and makes cable management a lot more pleasant. In addition to this, the shape of the board was designed in an oval shape featuring ports all around the board thus allowing access to power and signal from all around the ROV and increasing flexibility in terms of component placement on the Orca.

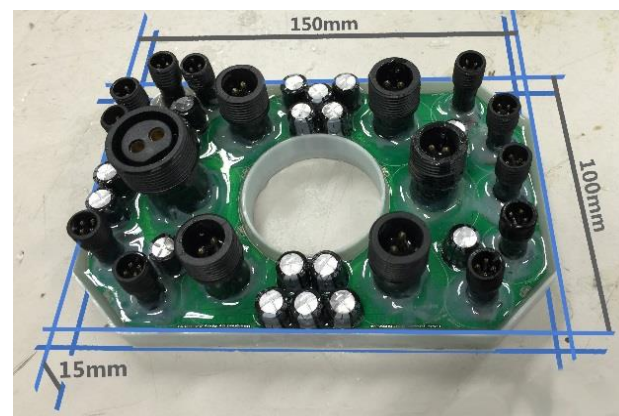


Figure 13 Orca's integrated power and CAN bus board



## Tether Cable

The Orca's tether is composed of four main wires: two wires for conducting power (positive and negative), an air pipe for the actuators and a CAT6 Ethernet cable for communication. For the power, Teflon coated silver plated copper wire is chosen for its thin and light properties, which contributes in minimizing the overall weight of the machine, and at the same time suitable for conducting large amount of current. The Orca utilizes a CAT6 Ethernet cable for handling video streams and CAN communication protocol. Out of the eight transmission pins, three are being used for the CAN transmission signals (CAN\_HI, CAN\_LOW, GND) and the rest of the pins act as analog signal input for cameras.



Figure 14 Orca's tether cable

Tether Mass in Air	Length	Mass per length
3.40 kg	30 meter	0.113 kg/m

Table 1 Tether mass and length of the Orca

## Camera Board

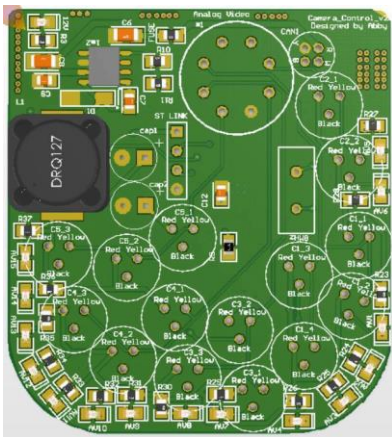


Figure 15 Orca's Camera Board

Epoxy Inc.'s approach to use mission specific manipulators is supported with the implementation of cameras placed at various positions. This year, fifteen cameras are implemented around the Orca. The cameras are placed in positions best suited for task specific manipulators to enable the pilot to have a finer driving experience and to perceive a better sense of the surrounding environment. To achieve this, Epoxy Inc.'s electronic engineer *Xinjie Yao* has designed and developed an in-house camera board that is able to support the cameras. The board is first designed in a prototyping software, Altium Designer, and developed before it is sent for manufacturing.

The camera board allows the control of multiple camera channels to stream real time video to the monitors by using MOSFET transistor as a switch. This enables the pilot to switch between cameras depending on

which ones are needed. With five dedicated pins from the Ethernet cable, five video streams can be displayed at the same time on the control box's monitors.

## Propulsion



Figure 16 Blue Robotics T200 Thrusters  
(retrieved from: [www.bluerobotics.com](http://www.bluerobotics.com))

(0.8125 m/s). T200 also has a much lower cost than CrustCrawler, making it cost effective and the more suitable choice for the Orca's propulsion.

Thruster	Weight in air	Max Forward Thrust Capacity at 12 V	Thrust-to-Weight Ratio
T200	344 g	34.7 N	3.96 (the Orca)
CrustCrawler	453 g	26.7 N	1.40

Table 2 Thruster Performance Comparison; T200 as used in Orca, CrustCrawler as used in Stingray

To drive the motors, Epoxsea Inc. electronic engineers *Hans Ryan Tanubrata* and *Yau Pun Chen* have designed a new motor driver which is a lot more compact than those used on the previous ROVs in order to help shed weight. Furthermore, the firmware algorithm designed for the motor drivers allows for more stability while roaming and during acceleration due to more precise control over the 65536 different levels of PWM input into the commercial *Seaking 30A – V3* electronic speed controller (ESC).



Figure 17 Seaking 30A-V3 ESC (Source: www.hobbywingdirect.com)

## Software

As part of the minimalistic and light design approach, the software control system has been revamped from last year’s machine, Stingray, such that the Orca is controlled without the use of a microprocessor unit (MPU) in the machine. The removal of such powerful component from the machine provides some essential benefits, one of which is a faster and a more direct communication between the control-side with the machine thus making it easier to troubleshoot when a problem arises. The Orca is controlled directly from the control box (computer) at the shore side, which is responsible for the Orca’s movement, manipulators control, video stream from cameras, and feedback from sensors (as shown in Figure 18).The control box is connected to the Orca via CAN bus over the CAT6 cable. The CAN messages are received by the MCUs on board the Orca which are programmed independently.

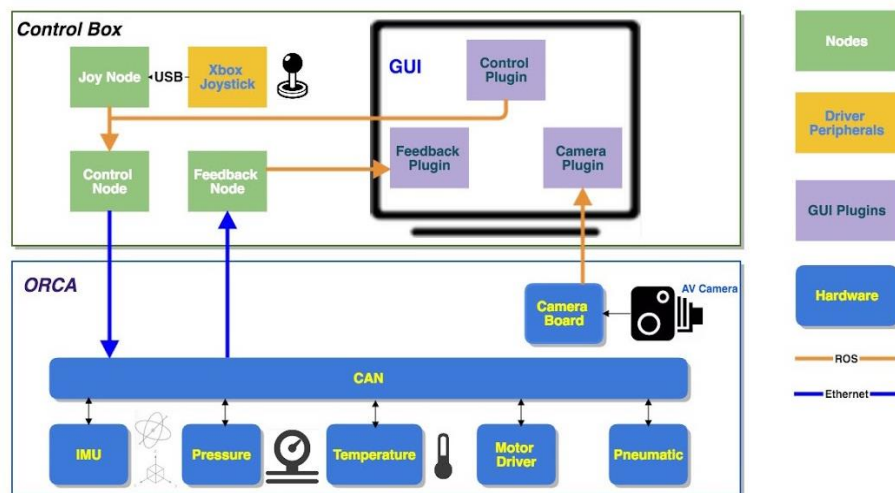


Figure 18 Software communication diagram

## Robot Operating System

The stability and collaborative software systems are some reasons that ROS is still being implemented in this year’s software architecture. Choosing to use ROS was instrumental in the development of the Orca’s software as it helped bridge different platforms together. By employing ROS, similar to multithreaded programs, the different programs developed could be simultaneously run as different nodes. This allowed for an elegant software infrastructure that was extremely stable. If one node were to crash from the system due to any errors or bugs, it would



Figure 19 Separate computers being collaboratively used to control the Orca

not bring the rest of the system down with it. The rest of the system would continue operating as if the faulty node were simply not sending any messages to anything, preventing the Orca from going totally offline. This also enables the swift pinpointing and debugging of malfunctioning programs.

## Inertial Measurement Unit and Pressure Sensor

The software architecture is developed in conjunction with the mechanical design approach to ease the completion of the missions. Hence, two feedback sensors are introduced into the Orca this year: an inertial measurement unit device (IMU) and pressure sensors. The IMU combines both accelerometer and gyroscope to get the Orca's linear acceleration and angular velocity. The device is responsible to get real-time feedback of the Orca's orientation, thus allowing the pilot to drive the Orca more efficiently. In addition to getting feedback, an automated stabilization system has been developed by *Cheng-Hsin Wuu and Gian Miguel De Mundo* with proportional and derivative control loop feedback mechanism to negate hydrodynamic disturbances, which in turn aids the pilot in completing the mission. The pressure sensor was utilized to maintain the Orca's depth automatically whereas the readings from the IMU are developed to ensure the Orca stays in position, turns or moves with precision. Implementation of such control comes in handy when the pilot is completing missions that require precise and stable movement, for instance the insertion of bolts to secure the wellhead cap and the connector to the power hub.



Figure 20 The Orca's IMU marker

## Graphical User Interface (GUI)

The GUI, developed by *Mang Tik Chiu*, was created to run in rqt, which is a Qt-based framework for GUI development in ROS. Through the GUI, real-time feedback of the motors' PWM, the manipulators' states, temperature and pressure can be displayed.

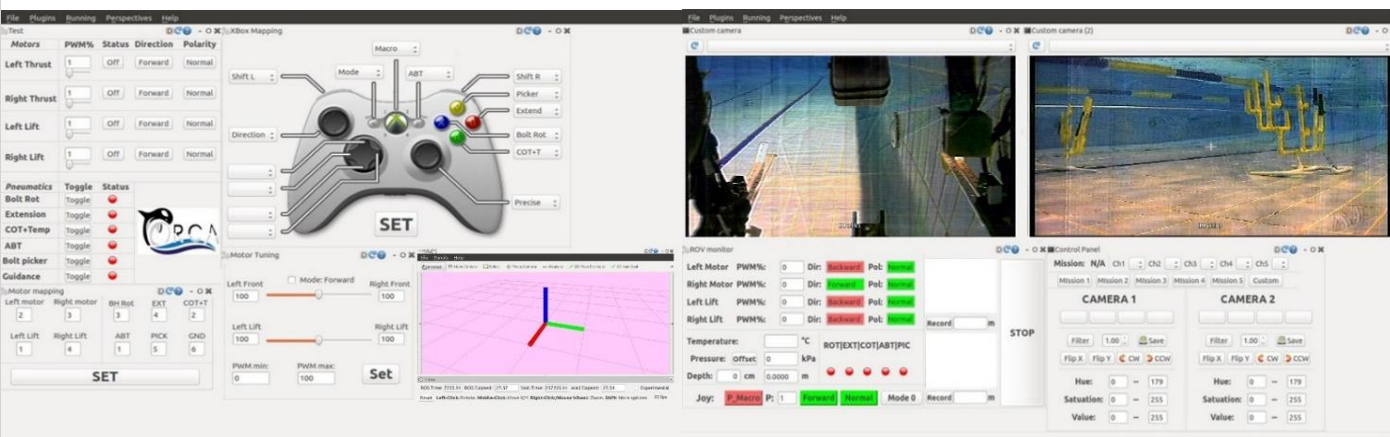


Figure 21 GUI with control and feedback layout

Figure 22 GUI with camera layout

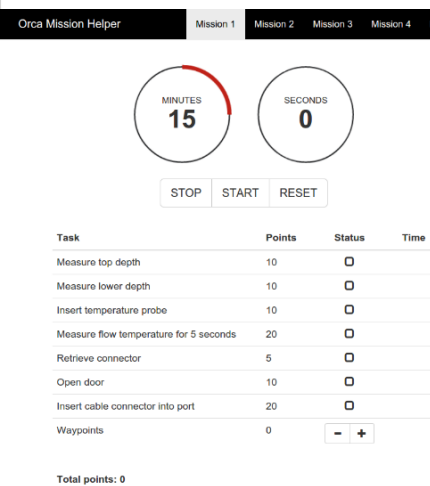
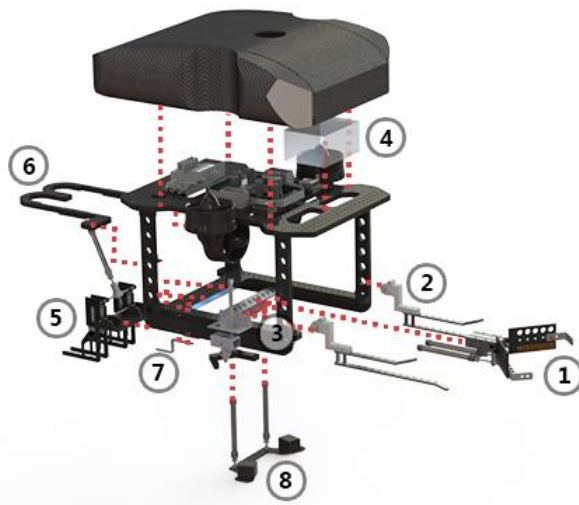


Figure 23 Mission helper UI

With the implementation of fifteen cameras this year, a camera plugin in the GUI is developed to intuitively handle the cameras. Up to five cameras can be displayed at once to prevent our driver from being overwhelmed with the amount of cameras. Another feature used is object tracking through the cameras. For the Deepwater Coral Study task, when observing the corals, the color yellow can be isolated to more easily understand the state of the corals. To better plan for the mission, *Randitya Setyawan Mohamad* designed a web application UI to help the Orca's pilot in keeping track of the tasks at hand. This Mission Helper features a timer, a calculator to measure the error of our temperature and depth readings and a tool to keep track of the status of each CubeSat. During practice runs, the mission helper serves to evaluate the performance of the pilot and to identify which area of the ROV needed improvement by keeping a record of the time taken to accomplish each task.

# Mission Specifics

To cope with the tasks and requirements proposed by MATE and Oceanering, the Orca features several passive and active manipulators that can facilitate the completion of certain tasks and functionalities.



## Outer Space Mission

- 1 Main Gripper
- 2 Connector Guidance
- 3 Temperature Probe

## Inner Space Missions

- 4 Lift Box
- 5 Bolt Hand
- 6 Bolt Hand Guidance
- 7 Oil Sample Collector
- 8 CubeSats Cameras

Figure 24 Mission specific manipulators

## Outer Space (Europa)

### Main Gripper

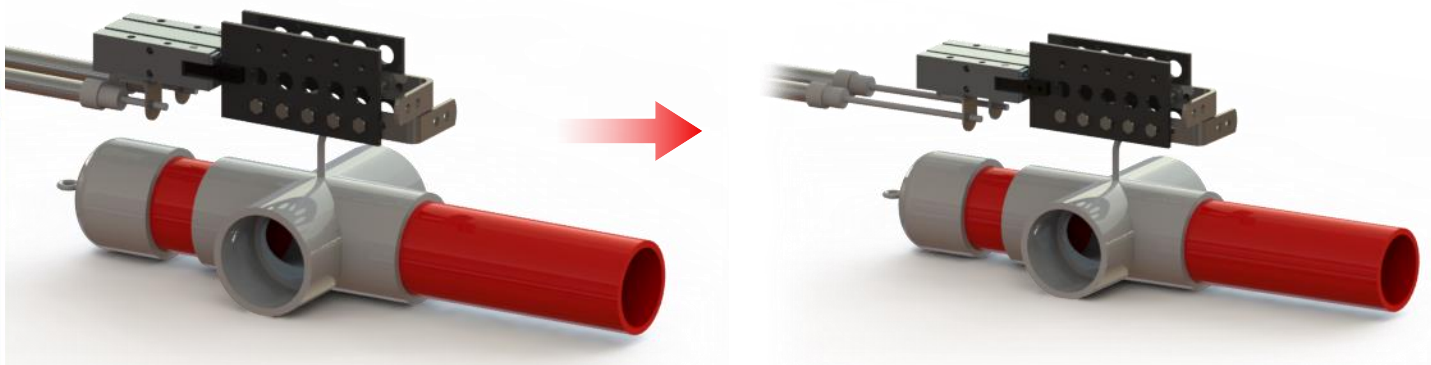


Figure 25 Main Gripper holding the connector (left), Main Gripper extended (right)

Given the overall dimension of the Orca and the number of tasks this year, it would not have been ideal to have a large number of mission-specific manipulators. With this, the Gripper Hand was designed by *Randitya Setyawan Mohamad* to accomplish several sets of tasks, namely, inserting the connector into the port of the power and communications hub, retrieving *Madrepora prolifera* coral samples, and capping a decommissioned oil wellhead. This manipulator is an adaptation of the Whale's "The Claw" from 2013, which was designed in order for Whale to have a strong and versatile manipulator. The plate that makes up the hand is made out of 3 mm fiberboard with aluminum tips to create a claw-shape design, which opens and closes when actuated. By adding multiple pairs of holes and bolts, and also a line of rubber padding made out of a timing belt, an improved grip

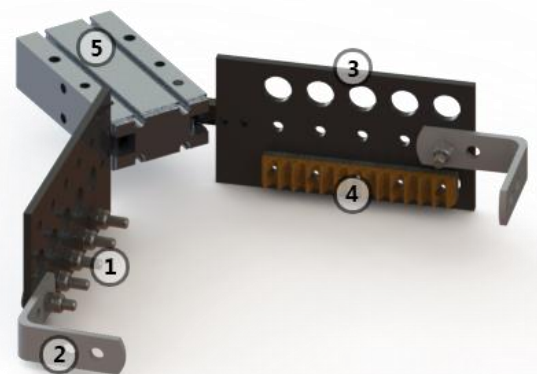


Figure 26 bolts (1), aluminium bracket (2), fiberboard (3), rubber padding (4), angular actuator (5)

can be achieved for better handling of the connector and coral samples. On the other hand, the aluminum tips are used to provide necessary grip when picking up the flange and wellhead cap by allowing four or more contact points on the item, ergo, increasing the safekeeping of the grip even under high accelerations of the ROV.

The manipulator has undergone hours of testing and was fine-tuned over time, such that it is able to have the best possible grip on the several objects it needs to collect throughout the five missions.

Attached to the gripper is a set of pneumatic cylinders that can be extended and retracted. This added feature to the claw-like grippers is to give an extra degree of freedom, thus greater flexibility to the driver. This greater mobility of the gripper would allow the Orca's driver to complete tasks involving said gripper in a timelier manner and with greater ease.

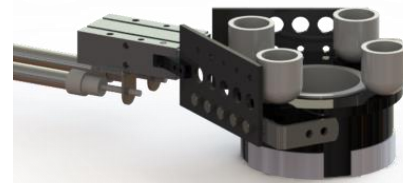


Figure 27 Main Gripper holding the wellhead cap

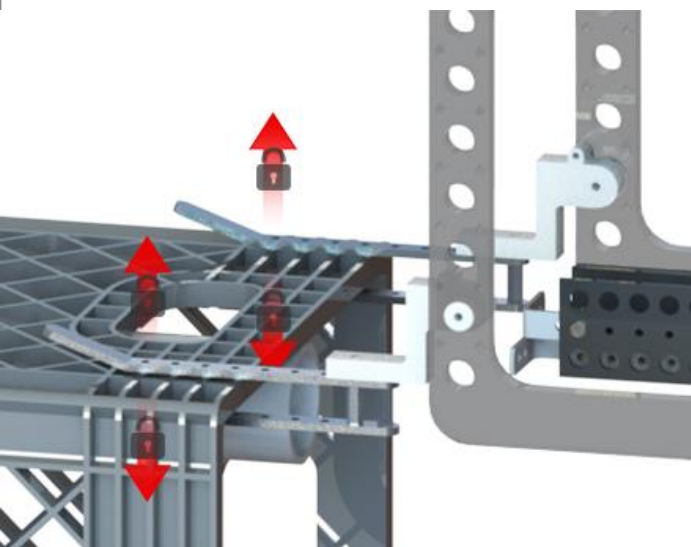


Figure 28 Guidance engaged to the Power- Communication Hub, locking Y-axis movement

## Connector Guidance

In order to facilitate the insertion of the connector, in a faintly larger diameter hole, for the pilot, a mechanical guidance was specifically designed and placed on the inner sides of the frame like in Figure 28. This design features two aluminum plates that face parallel to each other, which was designed specifically to act as a guide during the insertion of the connector. The separation between the two plates was premeditated such that it allows the pilot to effectively aim for the edges of the crate (The ESP hub) yet limit the vertical movement of the Orca to aid the pilot in inserting the connector swiftly. An added functionality to this guidance is that the pilot can use it to open the door of the ESP hub with ease.

With the goal of effectiveness of the payloads and with cost effectiveness in mind, the guidance was designed and tweaked to enable the pick-up and drop off of the CubeSats. The two thin aluminum plates feature a design that goes from having a broader end to a narrower end, essentially a tip. This requires the pilot to simply aim for the sides of the CubeSats and the Orca as ascend upwards, the CubeSat would rest at an angle of depression, allowing the cameras placed at the bottom of the Orca to capture the serial number. The approach has been tried and tested with a couple of variations in sizes and shapes, which led to the finalized model, allowing the pilot to pick up and drop off the CubeSats with ease. Moreover, the Orca can be made more compact in size as before the deployment of the ROV as the main gripper guidance can be made vertical and locked into the vertical frame (foldable) such that the Orca can be packaged into a more compact form.



Figure 29 Guidance securely carries two CubeSats

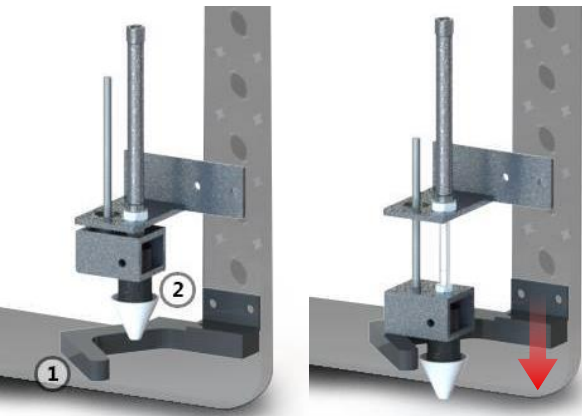


Figure 30 Temperature Probe guidance (1), temperature probe (2) when retracted (left) and extended (right)

## Temperature Probe

In order to measure the temperature of water emerging from a vent, the Temperature Probe was designed by *Tang Can-Yao*, in collaboration with *Xinjie Yao* from the electronics division. The approach for this task in the mission is quite straightforward, as the aim of the task is to maneuver the Orca to approach the emerging vent at close proximity and push the probe in into the opening. Once the Orca is in close proximity of the vent, the guide placed at the bottom of the probe would guide the Orca to align the probe with the vent's opening. This would then allow for a pneumatic actuator to drive the temperature probe into the vent to obtain the required temperature reading.

*ds18b20* was chosen as our temperature sensor due to its suitability in operating either in the Gulf of Mexico or in the cold water of Europa (ranging from -55 to 125 degree Celsius).

The *ds18b20* provides 8-12 bits resolution with one wire protocol, where when operated with our STM32 MCU, would provide us with a more accurate resolution (up to 0.04 degree Celsius\*) as opposed to using an 8-bit *Arduino* MCU (up to 0.70 degree Celsius). To minimize the random errors, three sensors are integrated into one circuit board which is then fitted into a carbon-tube housing.

## Pressure Probe

To find the thickness of the ice and the depth of the ocean floor, a pressure probe was designed by *Ngai Cheung*. The device is composed of two *MPX4250* pressure sensors which can operate in the range of 0-250 kPa. Multiple sensor units are implemented in both boards for averaging the systematic bias of each individual sensor, thus allowing improved readings with better signal to noise ratio. The sensors' inputs are processed by the MCU through the analog to digital converter (ADC) which provides an accurate resolution of up to 0.006 meter<sup>^</sup>. To get the thickness and the depth of the ocean, the device is placed alongside a camera, so that the Orca has to simply maneuver and face the respective depth marks.



Figure 31 Depth reading as shown in GUI

## Inner Space (Gulf of Mexico)

### Bolt Hand

To pick up and insert the bolts efficiently, a mission specific manipulator was required. The manipulator consists of two pairs of forked fingers made from glass fiber boards, each complemented by a pneumatic gripper. These are connected in parallel and joined together by a carbon fiber rod, creating a lever mechanism that is driven by a linear actuator. Composites is the primary choice of material for its specific strength and moreover, Epoxsea Inc. Over the years has had profound experience in composites manufacturing. The forked fingers are designed to lift the bolt from the elevator, and then secure them by the pneumatic gripper. Two pairs of forked fingers are installed to allow the Orca to hold two bolts at any time, minimizing the travel back and forth between the wellhead and the elevator. The lever mechanism allows the bolts to be rotated 90 degrees when the linear actuator is extended, making the insertion of bolts into the flange and wellhead cap possible (refer to Figure 32 on the next page).

\*  $ds18b20$  range of -55 - 125 degree Celsius in the STM32 12-bit MCU =  $\frac{180}{2^{12}} \approx 0.04$  degree Celsius

^  $MPX4250$  range of 0-25 m in the STM32 12-bit MCU =  $\frac{25}{2^{12}} \approx 0.006$  m

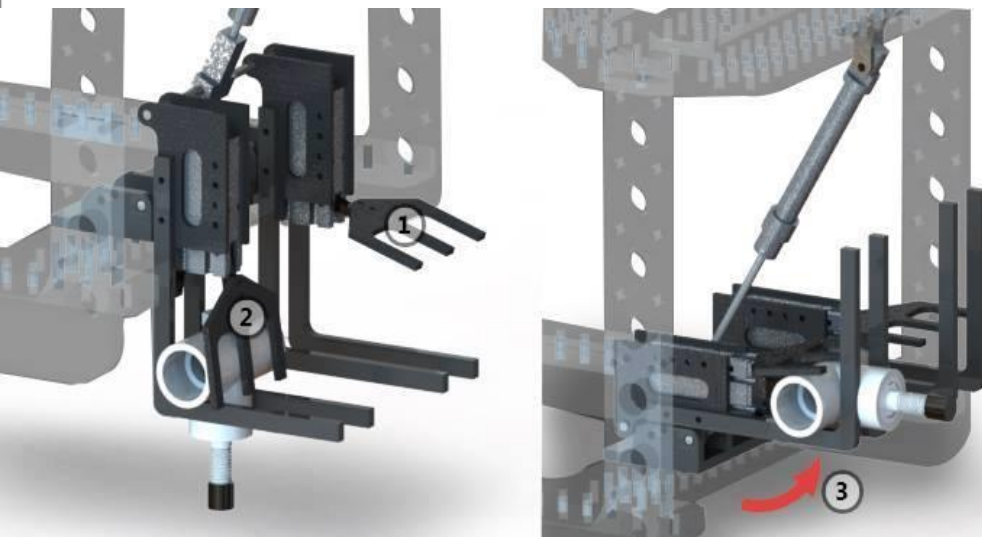


Figure 32 Open (1), closed (2) and rotated (3) bolt hands

Given that the bolts need to be inserted in a relatively constricted hole, a mechanical guidance was implemented to aid the pilot in aiming for the opening to insert the bolts more efficiently. It works such that the pilot would need to align the inner curvature of the guidance around the wellhead itself and hover the Orca down, where the pilot can rest on top of the flange and move forward to insert the bolts.

With the aim of having manipulators that are versatile and effective in terms of functionality yet maintaining a compact form factor, the bolt hand is also designed to pick up the oil sample. The bottom plate features three brackets such that the pilot would simply need to accumulate the oil sample by



Figure 33 Bolt Hand grabbing an oil sample

troweling it in the confined space and the forked finger, which is also responsible for securing the bolts, can secure the oil sample. Once the oil sample has been collected, it can be dropped off in the basket, along with the *Madrepora prolifera* coral samples, that is deployed along with the Orca before it descends to complete the missions. This approach helps conserve crucial space on the Orca and making the most effective use of the payloads that the Orca features.

### Collection Basket

A collection basket is used to retrieve the *Madrepora prolifera* corals and oil samples. The basket is brought down by the Orca to the seabed, where samples collected by the ROV can be dropped off into the basket during the mission. Then, when all samples are collected, the basket can be retrieved by the shore-side crews, whenever needed. The basket itself is reused from an existing commercial basket, and connected to it is a 20-meter rope that is able to sustain the weight of the samples and the basket during retrieval.



Figure 34 Collection basket with ropes attached on each corners

# Safety

## Safety Philosophy

Safety is of utmost importance and is taken very seriously here at Epoxsea Inc. A multitude of safety measures and protocols are taken to ensure that incidents can be averted as we believe that all members have the right to a safe working environment and that all accidents are preventable.

## Lab Safety Protocols

During the design and development phase of the Orca, a number of safety protocols had to be followed when working in the lab. Appropriate safety equipment were used when handling power tools and machinery. When using the grinder, drills and saw, members were obliged to wear hearing protectors, protective goggles and masks. This reduced the susceptibility of our members to suffer from injuries such as ear damage and eye irritation from infinitesimal fibers. The overhead ventilation system has to be used when soldering electronic components and using epoxy so as to remove the fume generated. Our mechanical engineers also wore gas masks when using their power tools to prevent the inhalation of any particulate matter, such as those created by grinding carbon fiber and aluminum. When using the air pump, the pressure gauge had to be monitored to keep the pump's pressure at 2.75 bar (275 kPa).



Figure 35 Epoxsea engineers soldering components

## Testing Safety Protocols

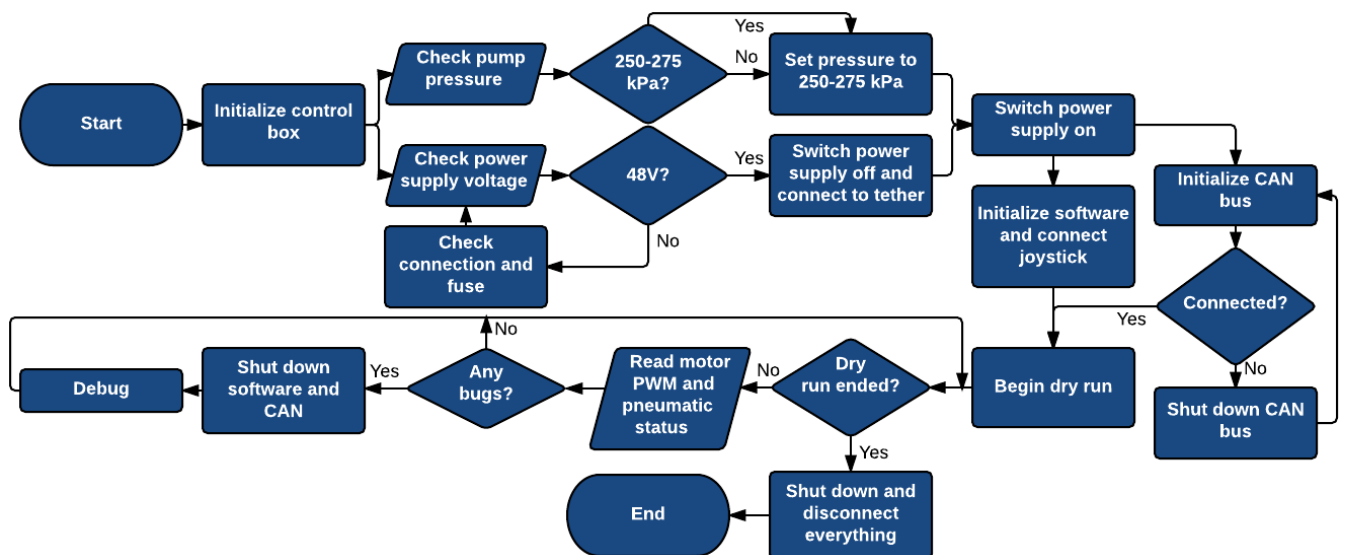


Figure 36 Dry run procedures and protocols

During testing, Epoxsea Inc. always emphasized on keeping our members safe. In order to accomplish this, a safety checklist was made, and members had to strictly abide by the rules stated in the checklist to ensure their safety. One example is the current drawn from the power socket and air pressure in the air pump are both checked before operating the Orca to prevent any safety hazards, such as overdrawing current or over-pressurizing the air pump. Moreover, members should remove their hands from the Orca before turning the power on, and they should refrain from touching the Orca while under operation. The tether also had to be neatly placed on the ground without being tangled to avoid any tripping hazards.



## Safety Features

Throughout the development of the Orca, dry runs of the ROV were frequently held to test and debug the mechanical pneumatic systems and electronic components before putting the Orca into the water. During dry tests, procedures have to strictly be followed to safeguard the members and the Orca.

On the software side, a fail-safe contingency was developed in case of any malfunction regarding the motors. The MCU is programmed with a safety watchdog timer, where it checks the motor drivers to see if they receive any instructions. In the event of motor driver failure where they fail to receive anything after one second, a command is sent to all motor drivers to automatically shut them down.



Figure 37 Orca's thruster with safety sticker

In order to ensure the safety of the diver and the members when working on the Orca, sharp edges are filed off and warning stickers are placed on the motors to indicate clearly that caution has to be taken when working near these areas.

On the electronics side, an emergency kill box is connected between the 48V power supply and the tether to cut the current being sent to the Orca. It must always be placed in the most accessible area possible to ensure quick reactions to emergencies. For instance, if the Orca's electronic components malfunction while operating in the water, the kill box must be pressed to immediately stop the Orca from operating and being further damaged.



Figure 38 Emergency kill box with voltage reading from a digital screen

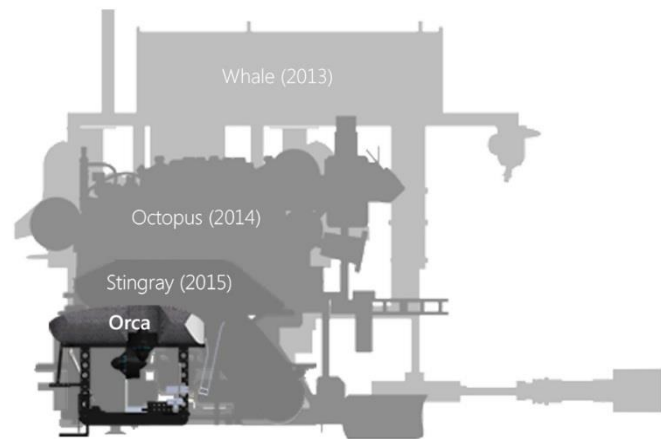
## Safety Checklist

- Connect the power supply to the socket, and make sure that the voltage output of both the power supply and the tether is 48V.
- Turn the air pump on, make sure that the pressure does not exceed 275 kPa, and that there are no air leaks.
- Check for loose objects, exposed wires or any other signs of physical damage present on the Orca.
- Check that all wires are securely and appropriately connected.
- Initialize the software in the control box, and monitor the statuses of the electronics and pneumatics systems on the Orca.
- Begin dry run of the Orca to check that the motors and manipulators are working safely and properly.
- If any of the above cannot be met, resolve the concerned problem(s) as appropriately and swiftly as possible to ensure optimal deployment of the Orca.

# Challenges

## Size Efficiency

Epoxsea Inc. has been known to develop ROVs in a rather larger form factor over the years. This year, Epoxsea Inc. set out to build one of the smallest and lightest ROV yet possessing the capability to trump its predecessors. This, however, brought in what was one of our biggest challenges: trying to find a balance between the dimensions of the Orca and the number of mission specific manipulators along with their placement. Initially, our mechanical engineers had designed and tested several mission specific manipulators. Over time, it became evident that the space was getting too confined and made maintenance and repair work a little frantic, thus prompting our engineers to find a way to design or even modify the existing manipulators that are not only mission specific but can also be used to carry out several tasks. Examples of such manipulators aboard the Orca include the Main Gripper and the Bolt Hand. Both these manipulators have been tweaked to the best configuration to ensure that the pilot can carry out the tasks efficiently and swiftly.



ROV	Dimension (mm) <sup>*</sup>	Weight (kg) <sup>*</sup>
Stingray (2015)	860 x 450 x 540	21.72
Orca (2016)	510 x 470 x 400	11.50

<sup>\*</sup>Length x Width x Height <sup>\*</sup>in air; excluding tether

Figure 39 Design Evolution of Epoxsea's ROV

## Placement of Manipulators

The first plan of action was to allocate the weight to the required core components such as the tether, the electronic components and pneumatic manifold including the valves to determine how much weight could be allocated towards the manipulators. When designing the mission specific manipulators, a lot of emphasis was placed on what materials the manipulators would be made out of, to shed as much weight as possible, while still maintaining its integrity. Next, with the given dimensions of the Orca, the placement of these manipulators had to be well thought out so that their functionality would not be hindered while still maintaining a well-balanced setting with all the manipulators in place. However, after the process of prototyping and modifications that followed, a few of the manipulators such as the oil sample collector and the main gripper, required more space than anticipated, leading the Orca to be a little more cramped than we had hoped for. Nonetheless, even with the current setting, the functionality of the manipulators has not been thwarted.

## Interpersonal

With one of Epoxsea Inc.'s senior members having graduated and several others having gone on exchange, Epoxsea Inc. have enlisted 12 new members alongside the 2 continuing senior members. To ensure the establishment collaborative team environment, we had team bonding activities, such as hiking, beach barbecues, and frequent meal gatherings to find the best way to communicate with each other. Spending time after the formation of the team allowed us to get to know each other, and overcome any language barriers. Moreover, a driving force for improved team collaboration is that



Figure 40 Preparing for a beach trip for team bonding

member's roles and responsibility are clearly defined to work together successfully as miscommunication can truly undermine the team's working environment. Working on the Orca over the past few months brought in opportunities for collaborative work across different disciplines and backgrounds, resulting in the team working closer together.

## Troubleshooting

The Orca has undergone more than 70 hours of testing under water. Before launching the Orca into water, dry-runs were conducted with close supervision ensure the machine's safety and to test the entire system such as its power, feedback, pneumatic manipulator, camera's angle and motors' performance (refer to Safety Checklist on page 16). Problems encountered during the testing were solved using the Five-Step troubleshooting technique. The troubleshooting began with verifying whether a problem exists in the first place or whether it arises from operational/human error. Once verified, we then identify and isolate the cause of the problem. With courtesy to the software and hardware architecture of the machine, this can be done quickly with two approaches – by using the software feedback system to identify the malfunctioning component or by connecting test equipment to the integrated electronic components. For examples, in the case if one of the thrusters stops working, we can simply check the LED indicator in our integrated motor driver and ESC board of our machine. Or, in the case when communication is lost, an in-house indicator board can be simply attached and the LED indicator can be monitored to see if one of the ports has malfunctioned. When one cause of problem has been isolated, we move on to check on another possible source of the problem, for instance, the power regulator and power source to the board. The next course of action is to correct the cause of the problem considering some factors in mind to make the decision, such as duration and magnitude of repair, cost analysis and material availability. Once the corrective action has been taken, the problems are verified to see if they have been resolved. This is done with thorough analysis of the repaired area of the machine: to check the integrity of the component and to make sure that it does not surface another problem. The last step of the troubleshooting is to follow up and prevent the same problem from happening in the future. This involves taking preventive measures by doing a maintenance check on a regular basis, adopting a safe preventive working or manufacturing procedure, and most importantly documenting all the problems encountered for future references.

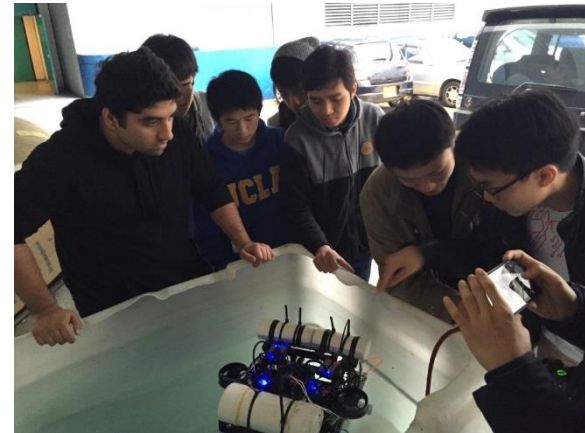


Figure 41 Members observing the performance of the Orca

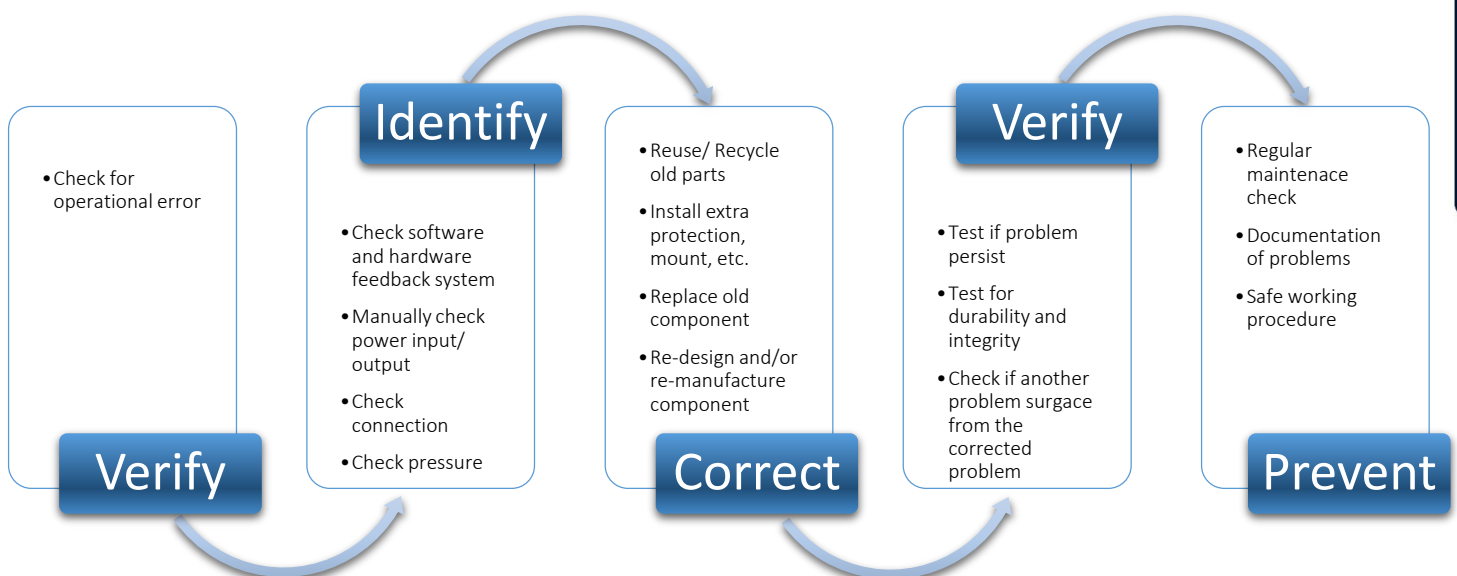


Figure 42 The five-steps troubleshooting technique of the Orca

# Lessons Learned

## Electronics tube

This year, Epoxsea Inc. decided to forgo the use of an electronics tube in the Orca as it was not space efficient and given the dimensions of the Orca, an attempt to conserve space had to be made. As a result, each electronic component (e.g. Electronic Speed Controllers, regulators, motor drivers, camera board) features its own 3D-printed housing that is waterproofed using epoxy instead of using an electronics tube to house all of our electronic components. This approach towards waterproofing eliminates the concern of water leakage, a concern that would arise when using electronics tube, and hence also improves durability. Moreover, with the electronic components arranged and mounted on the top side of the frame in the Orca, the cables running from the electronic components are all localized in one region making maintenance a lot easier when compared to the previous years.

## Cable Management

Cable management has always been a frontrunner when it comes to listing out the challenges we face each year. To deal with this problem, all the electronics are constructed to have a certain architecture such that they are combined into a centralized single board and then mounted onto the top side of the frame. This proved to be beneficial during maintenance and also conserved space for the other components to be installed on the Orca, such as the guidance for the Main Gripper. Nevertheless, focus was heavily placed on making the access for maintenance more convenient. However, this decision created an unforeseen outcome: cable mess. Since the electronics are all on top of the frame, the bundles of cables became messy and disarrayed. The main reason for this was the positioning of the components had not been premeditated well enough. This problem was then resolved by resizing and modifying the main board such that cables can be split in two lateral (left and right) regions. In addition to this, the length of each cable is carefully planned and adjusted so that it will not dangle.

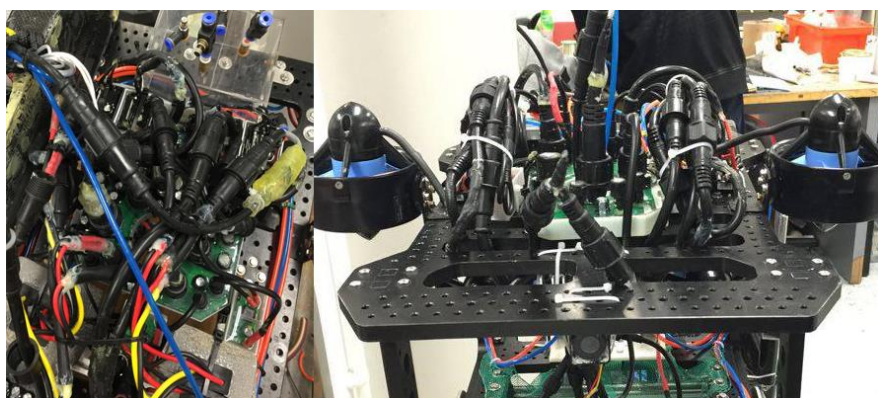


Figure 43 Cable mess (left); reorganized cables (right)

## Research

Major changes have been very incremental in Epoxsea Inc.'s preceding ROVs. However, for the Orca, we wanted to bring about some changes to existing systems and also attempt to implement a few new ones to facilitate our hand in further improving our ROVs. This necessitated a lot of research and development time. During the R&D time and from past years' experience, it was clear that time management and documentation are two key aspects for successful research, which we believe to be critical for long-term success and development as a company. The Orca boasts a few of the desired changes that had undergone research and development, the change of material for the frame is one example. Even though not everything that we researched were employed, allowing the new members to have a go at this process has made both the newer and continuing members better researchers and has help us acquire more knowledge in our areas of interest. To ensure that the knowledge can be shared with other members and future teams, findings and potential areas of research would be documented through articles, photos and videos and uploaded to our knowledge database.

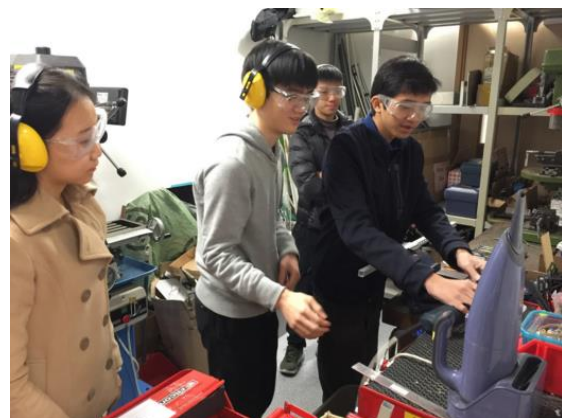


Figure 44 Cross-training among Epoxsea Inc. divisions

# Future Improvements

## IMU Implementation

One new research implementation this year is the use of IMU in the Orca. The combination of accelerometer and gyroscope allows control crew to get real time orientation and movement of the machine; whether it is tilting, rolling or yawing or moving in surge, sway or heave. This has significantly helped the crew obtain a more refined perception of the environment and help coordinate the Orca's movement. The device has also been used to perform automated and precise movement by utilizing a proportional control loop feedback mechanism, such as maneuvering into a fixed angle. However, as in many other applications, IMU device incorporate biases that when not correctly dealt with, would give an inaccurate feedback. To deal with that, our software engineers had implemented a commonly used complementary filter to tune the input accordingly. In the future, adding magnetometer alongside the accelerometer and gyroscope in the IMU would allow for a more accurate feedback of information. Furthermore, a more refined noise filtering algorithm such as Kalman filter could be implemented to minimize inaccuracies in the readings.



Figure 45 Accelerometer and gyroscope in the IMU



Figure 46 Self-made regulator

## In-House Regulator

Epoxsea Inc.'s years of experience in building ROVs have allowed for plenty of insights on how to develop a specific hardware that can deliver excellent performance while being cost-effective. So, Epoxsea Inc. has been trying to transition from using commercial components to developing in-house components that can be personalized for certain specifications and adapt to designated functions. This year, Epoxsea Inc. developed and manufactured in-house regulators for the Orca. After a few iterations of the regulator, Epoxsea Inc. compared the performance of the in-house regulators with commercial ones. Even though the in-house regulators worked well, commercial regulators gave a more stable and predictable performance. To ensure that the Orca can run at its maximum potential and capability, Epoxsea Inc. opted to use commercial regulators instead. In the future, Epoxsea Inc. hopes to further improve and test the in-house regulators by utilizing additional filtering to reduce heat and transient noise, and adding more capacitors to further stabilize the current; yet making the regulators as compact and cost effective as possible.

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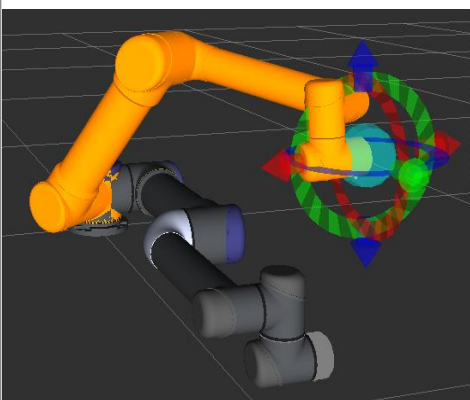


Figure 47 Industrial manipulator simulation in Gazebo; retrieved from: <https://chrisjpaxton.files.wordpress.com/2014/03/moveit-ur5-rviz.png>

## Simulation Platform

Over the years, one problem that Epoxsea Inc. discovered when developing ROVs is the difficulty in measuring how well the machine can perform before actually testing it in the water. This leads to a lot of crucial time being wasted on experimenting and prototyping which is not very cost efficient. For example, a manipulator design that seems to perform well during the dry test ends up not working out as well in practice when underwater. To solve this, our software engineers have began research and development on developing a 3D simulators of the machine and its manipulators. In the future, this would serve as a testing platform of the ROV before launching it into the water. With our current software platform, ROS, we have been able to expand our system into building a 3D rigid body simulation using Gazebo. This would allow us to test the machine balance, movement stability, manipulator model, and its performance at an earlier stage.

## Reflections



Figure 48 Epoxsea's members: Xinjie Yao (Left), Randitya Setyawan Mohamad (Middle), Hongseo Yoon (Right)

### Xinjie Yao (China)

During the preparation for the competition, I, as a new member who has no former experience in electronic engineering, am equipped with a barrage of new skills and gain a memorable experience working in a team where teammates have different cultural backgrounds. It encouraged me to learn more about the technology of the world and open a new door towards the engineering world. Working in the HKUST ROV team has offered me a platform to broaden my horizon and have a quick look at what happens on the other side of the world. Processing a global outlook is the first step to becoming a global citizen. Not only did I gain the skills in building a robot and knowledge in hardware but also the way to practice my time management and communication skills.

### Randitya Setyawan Mohamad (Indonesia)

I would like to thank the HKUST ROV Team for allowing me to participate in the MATE ROV competition. Hours of work in the lab finally came to fruition when I first saw our robot working properly. Working as a mechanical engineer for the team, I have acquired new skills such as good workmanship and how to design a robot, skills that are not taught in classroom in the first year of university. Apart from the technical knowledge, this competition has also taught me entrepreneurship skills which will be beneficial for my personal growth. Having gained new experience and skills, I am eager to come back next year to do better.

### Hongseo Yoon (South Korea)

Joining the HKUST ROV team has given me a precious experience and excitement that would mark the highlight of my first year in university. As a new hardware developer member of the team, there had been a lot to learn and practice in terms of the technical skills in developing the hardware for the ROV. This experience that I had was not only a fruitful experience for me as I was able to acquire the skills and knowledge, but also a very valuable one, as I was able to share a lot of irreplaceable moments and memories with the team members and learn the essence of teamwork through those. Besides those memorable experiences, my participation in the ROV team allowed me to explore the field of ROV development at a very advanced level and this has definitely facilitated the growth in my interest in underwater robotics.

# Budget Report

The following is the budget report for the development of the Orca during 2015-2016. In total, the Orca costs US\$ 5,566.64 to develop, with US\$ 14,607.18 in sponsorship.

Item No.	Sponsor	Remarks	Price (HKD)
1	HKUST School of Engineering	Finances	82,000.00
2	RS Components Ltd.	Electronic Components	8,020.43
3	Dassault Systems	Solidworks Student Edition (20 Licenses)	23,383.56
<b>Sub Total</b>			<b>113,403.99</b>
<b>Grand Total (1 USD = 7.76358 HKD)</b>			<b>US\$ 14,607.18</b>

Table 3 Table of sponsorship received by Epoxsea Inc.

Item No.	Item Name	Quantity	Price (RMB)	Price (HKD)
1	12 Hour Epoxy	N/A		1,200.00
2	3D Printed Electronic casing	N/A		1000.00
3	5 Minute Epoxy	30 packs		876.00
4	Air compressor (re-used)	1		
5	HDPE Frame	1	4,800.00	
6	AV Cameras	15	1,303.00	
7	Brushless Driver	4	1,584.00	
8	Brushless Thrusters	4		5,248.18
9	Buoyancy Foam	1		116.00
10	Cable Zip Ties	10		362.00
11	Camera Lens	15	200.00	
12	Carbon Fibre	2m roll	1,000.00	
13	Electronic Components	N/A	1,450.00	
14	Manipulator Components	N/A	10,000.00	
15	O-rings	N/A	100.00	
16	PCB Boards	10	879.00	
17	Pneumatic Cylinder: Gripper	3	327.00	
18	Pneumatic Cylinder: Linear Movement (re-used)	6		
19	Pneumatic Tubing	20m	200.00	
20	Power Connectors	30	200.00	
21	Power Regulators	10	3,680.00	
22	Power Splitter	2		46.00
23	Solenoid Valves	8	640.00	
24	Tether Cabling	1		1,253.00
25	Underwater LED strip	1	133.00	
26	Valves, Pipe Fittings, & Pressure Regulators	N/A	515.00	
27	Waterproof Cables & Connectors	N/A	773.00	
28	Xbox 360 Controller (re-used)	1		
<b>Sub Total</b>			<b>27,784.00</b>	<b>10,101.18</b>
<b>Total Cost in USD (1 USD = 6.51359 RMB = 7.76358 HKD)</b>			<b>US\$ 5,566.64</b>	

Table 4 Table of the expenditure for the Orca

Item No.	Item Name	Quantity	Price (USD)
1	Airfare (\$550 per person)	12	6,600.00
2	Hotel Bookings (\$95 per room per night)	3 rooms x 7 nights	1,995.00

Table 5 Table of estimated travel expenditure

# Corporate Social Responsibility

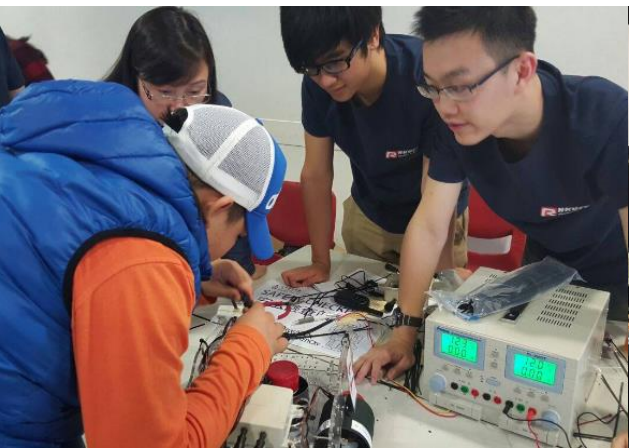


Figure 49 Gian Miguel Del Mundo and Mang Tik Chiu supervising a student during the Underwater Robotics Competition held by GCE and supported by Epoxsea, Inc.



Figure 50 Mang Tik Chiu engaging with Hong Kong Chief Executive Leung Chun-Ying



Figure 51 Christian Edwin Pranata and former member Andreas Widy promoting the Stingray during the InnoCarnival

Epoxsea Inc. consistent successes in both regional and international competitions has raised awareness of professionals in Hong Kong. As a result on January 2016, Epoxsea Inc. was honored to be invited as a guest speaker in a seminar held by the Hong Kong Institute of Engineers to share about our experience in building a ROV, participating in the international ROV MATE competition and the technology being implemented. In addition to that, Epoxsea Inc. was given the chance to promote and display our ROV in public at the InnoCarnival, an annual innovation and technology expo in Hong Kong. Epoxsea Inc. also took the initiative to inspire young engineers in our university by introducing them with underwater robotics applications, its challenges and how engineers can solve them.

In addition to knowledge sharing, Epoxsea Inc. has helped coordinated workshops with the support of The Institution of Engineering and Technology Hong Kong, and RS Components Ltd. The workshop was organized to help the local and international competing teams to design and build their own ROV. Our aim is to develop the skills and knowledge among the primary and secondary school students to design their own ROV. In April 2016, an Underwater Robot Competition, a community engagement project to build an ROV, was held with the support of Epoxsea Inc. The competition targets teams of primary and secondary school students, both from mainstream schools and those students who are underprivileged, ethnic minorities and disabled with the objectives of providing students with opportunities to understand the fun of Inclusion, Science, Technology, Engineering, Art, and Mathematics (iSTEAM).

## References

*Institute of Electrical and Electronics Engineers (IEEE) citation format is used.*

- [1] R.D. Christ and R.L. Wernli, Sr., *The ROV Manual*. Waltham, MA: Elsevier, 2014.
- [2] L. Joseph, *Mastering ROS for Robotics Programming*.
- [3] I. Saito (2014). ROS Tutorials [Online]. Available: <http://wiki.ros.org/ROS/Tutorials>



# Acknowledgements

Epoxysea Inc. would like to extend their most sincere gratitude to the following sponsors:

HKUST School of Engineering – for providing sponsorship and labs for Epoxysea Inc. to use.

HKUST Center for Global & Community Engagement (GCE) – for co-operating to provide advanced ROV training workshop and the ROV inclusion competition.

HKUST Design and Manufacturing Services Facility (DMSF) – for providing technical support and suggestions to Epoxysea Inc.

HKUST Student Affairs Office (SAO) – for allowing us to use the swimming pool for testing the Orca.

HKUST Creative Media Zone (CMZ) – for allowing us to use the AV studio for photoshoots and recording videos.

Dr Kam Tim Woo – our supervisor, whose guidance and advice helped us improve both our technical and non-technical skills.

Chun Yin Leung, Andreas Widy, and Sau Lak Law – our mentors, whose guidance and technical advice proved to be invaluable while developing the Orca.

MATE Center – for organizing the international competition, providing a platform for the growth of the entire community, and promoting STEM education around the world.

The Institution of Engineering and Technology, Hong Kong (IET HK) – for organizing the Hong Kong/Asia Regional of the MATE International ROV Competition 2016.

RS Components Ltd. – for sponsoring electronic equipment for Epoxysea Inc.

Dassault Systems – for providing SolidWorks Student Edition CAD software for Epoxysea Inc.

EDIS – for providing a hosted server for our website and internal use.



Figure 52 Logos of the acknowledged parties