Octopus: Technical Report

MATE ROV Competition 2014

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Abstract

This report illustrates the technical aspects of the Octopus, a ROV (Remotely Operated Vehicle) developed, designed and manufactured by Epoxsea Inc. The Octopus is a response to a request made by the Marine Advanced Technology Education Center for a ROV to discover, inspect and conserve a shipwreck and its environment. The Octopus takes advantage of advanced technologies such as a pneumatic system, the STM32F4 series of ARM microcontrollers and OpenWRT on the Raspberry Pi.

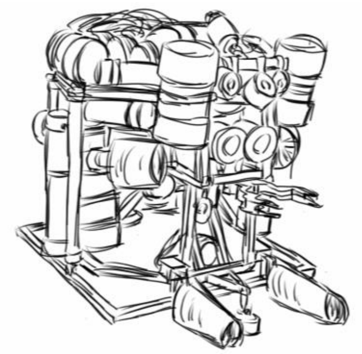


Figure 1: Concept sketch of the Octopus

The Octopus has a compact acrylic tube, which houses the main control system. To orientate itself in the water, and to effectively carry out the missions, the ROV is equipped with eight wide-angle digital cameras. For the propulsion of the robot we have taken advantage of six custom designed thrusters. The control program is based on the C# programming language and the communication between the ROV and the on shore control station is managed by a TP-Link router, which is connected via a network switch.

One of the major improvements compared to last year's robot is the emphasis on being compact and hence making it easier and more efficient to maneuver. A team of diverse and creative engineers designed the Octopus, taking advantage of up-to-date technology, which is available on the market, and out of the box thinking, Epoxsea Inc. has managed to build a ROV, which is capable to meet the requirement set forth by the MATE Centre.

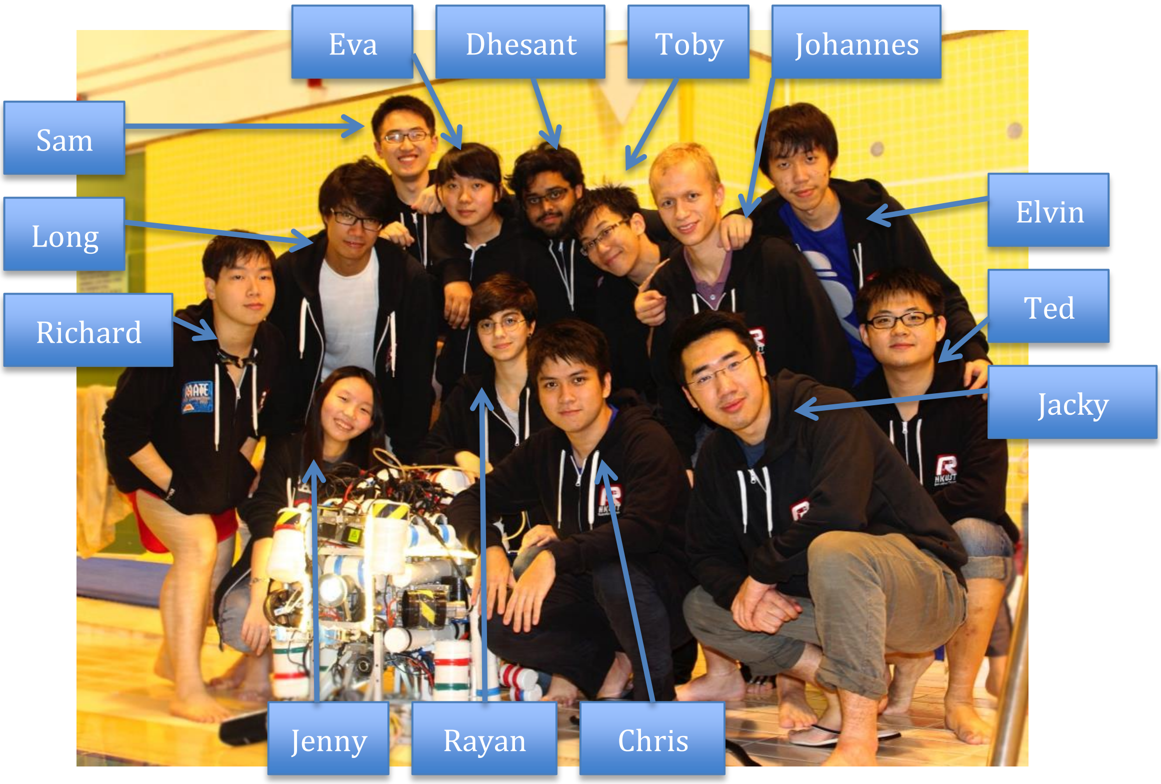


Figure 2: Group photo of the Epoxsea Inc. team with the Octopus

Budget Report

The following is the budget report for 2013-2014. This year we used USD 2,580.50 to development the ROV Octopus.

No	Sponsor	Remarks	Quantity	Price (USD)
1	HKUST School of Engineering	ROV Manufacture Sponsor		3,000.00
2	HKUST	Team Travelling Expenses		26,517.50
3	RS Components	Electronics Components	See Table 2	553.20
4	Dassault Systems	SolidWorks Student Edition	20 Licenses	2,000.00
5	IET PATW 2013 Awards	Cash		193.50
			Sub Total	**32,264.20**

Table 1: Table of Sponsorships for Epoxsea Inc.

	Part Name	RS Stock No.	Quantity	Price (USD)
1	AUIRFR3710Z	715-7645	200	348.30
2	ACS712ELCTR-20A-T	680-7135	50	6.50
3	ACS712ELCTR-05B-T	680-7131	10	37.50
4	AD8210YRZ	412-456	10	41.90
5	ATMEGA32U4-AU	715-3805	10	67.10
6	ATMEGA328P-AU	696-3092	10	32.90
7	SN74LVC8T245DBRG4	662-9105	40	9.70
8	LM2679S-ADJ/NOPB	533-5317	20	10.30
	Sub Total			**553.20**

Table 2: Table of sponsored components from RS Components

No	Item Name	Quantity	Price (USD)
1	Waterproof Connectors	45 pcs	77.35
2	Grinding plate and safety belt	1 pc	11.86
3	Drill Bits	3 sets	8.98
4	Velcro	5 meter	5.16
5	USB Hubs and Casing	1 pc	12.90
6	Underwater Lights	5 meter	24.37
7	Bearing and O-Rings for motors	18 sets	66.69
8	Pneumatic Cylinder: Rotary	6 pcs	153.90
9	Pneumatic Cylinder: Gripper (re-used)	3 pcs	63.97
10	Pneumatic Tubing	20 meter	32.06
11	PVC Pipes for Buoyancy	N/A	97.38
12	LAN Cables and Heads	5 sets	12.12
13	Clamps, tools, cutter	N/A	177.00
14	Solenoid Valves	10 pcs	109.49
15	Self-designed PCB Boards	10 sets	228.45
16	Safety Warning Signs & Other Items	20 sets	12.90
17	Webcams	7 pcs	115.43
18	5-Minute Epoxy	20 packs	90.29
19	TP-Link Routers	3 pcs	41.02
20	Aluminum Parts for the Frame	N/A	773.92
21	Propeller Shield	6 pcs	23.09
22	Thrusters	6 pcs	158.71
23	Propeller Blades	6 pcs	16.83
24	Camera Joints	6 pcs	32.06
25	Voltage Regulators	2 pcs	12.83
26	Acrylic Tubes	2 pcs	45.15
27	Heat Sink	10 pcs	37.83
28	O-Rings	N/A	9.62
29	Raspberry Pi Board	1 pc	40.00
30	STM32F4 Core Boards & MCU	2 sets	48.09
31	Valves, pipe fitting and air pressure controls	N/A	16.05
32	Xbox 360 Controller(re-used)	1 pc	25.00
		Sub Total	**2,580.50**

Table 3: Table of manufacture cost for the Octopus by Epoxsea Inc.

Summary

No	Item Description	Expenses (USD)	Sponsor (USD)
1	Total Sponsor Amount (see Table 1)		32,264.20
2	Design Cost (Solidworks License + RS Components Sponsor) (see Table 1)	(2,553.20)	
3	Manufacture Cost (see Table 3)	(2,580.50)	
4	Travelling Expenses (see Table 1)	(26,517.50)	
		Net	**613.00**

Table 4: Budget Summary for the Octopus by Epoxsea Inc.

Design Rationale

The key constraint for this year's ROV is the size limitations introduced by the MATE mission tasks, where the robot has to fit through a 75cm x75cm hole in order to enter the shipwreck. This meant that creating a compact and efficient ROV was the central point of focus from the initial stages of design; otherwise it would be near to impossible to accomplish the required tasks.

In addition, our principal objective was to streamline all the tasks into one trip, hence decreasing the travelling time of the Octopus. This involves designing and implementing many mission specific tools to perform the tasks, involving the subsystems described later. These were designed to complete the tasks accurately, without sacrificing time, which explains some of the design choices that we made.

This objective does create another constraint for us. In order to complete all the tasks at once, we would have to carry a lot of materials back to the shore, at the end of the timeframe, which includes an 7lb anchor, bottles, rope debris, etc. This means that we do not only need to have very powerful thrusters on the ROV to complete the tasks efficiently, but also to have enough space to carry around all the required objects.

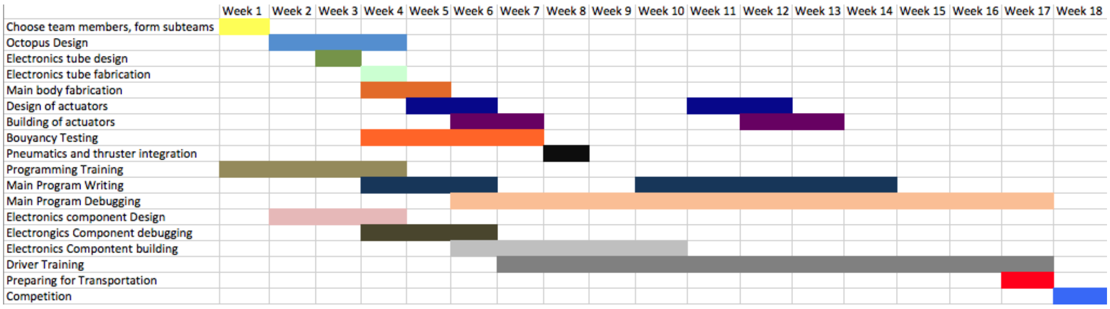


Figure 3: Gantt chart of the development timeframe for the Octopus

Because of the organizational structure in Epoxsea Inc. shown in Figure 4, we are able to divide the workload amongst the subdivisions, creating a much shorter timeframe, since the electronic design can be done at the same time as the mechanical design, which is also at the same time as programming training, as seen in Figure 3. However, as this is a real world project, there are delays and redesigns have to be reflected. For example, the design and building of actuators has been done twice, to account for modifications and upgrades.

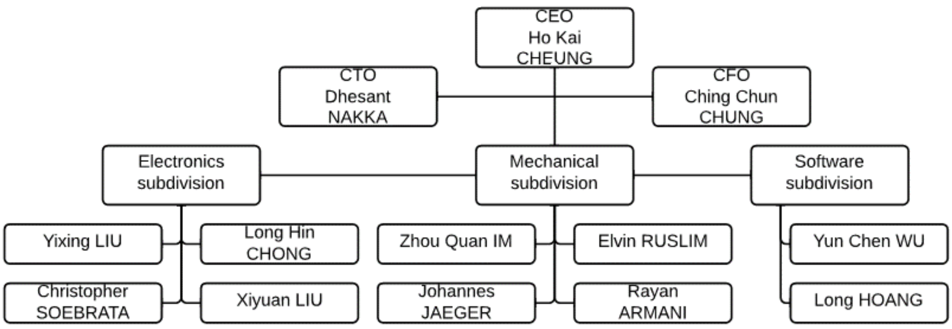


Figure 4: Organizational structure for Epoxsea Inc.

Safety Measures

This year we took safety as serious as during the previous years. Our lab is equipped with up to date equipment in order to reduce and hopefully eliminate injury. Epoxsea Inc. makes sure every system we built is of the highest safety standard and this is our company safety philosophy.

Figure 5: Warning stickers on ROV

Mechanical Safety

Epoxsea Inc. also has made sure that the robot is of the highest safety standard. We have installed appropriate warning stickers, as shown in Figure 5, to warn of thrusters. Furthermore, we have installed additional safety valves to possibly hazardous pneumatic systems, so in case they are accidentally activated, no one will be hurt.

Electrical Safety

Since the ROV has almost 2000 watts of power at its disposal, and there are many people present in the water with the ROV, electrical safety is one our key priorities at Epoxsea Inc. To address this safety issue, the main power supply is equipped with a 40A fuse, before it connects to the tether. As shown in Figure 6, is also an emergency stop button that will cut the power if necessary.

Figure 6: Emergency stop button

Each motor driver is equipped with 10A fuses and protection diodes across the motor, preventing any spikes in the supply that could create dangerous situations. Also, large capacitors are installed to ensure a smooth and stable voltage supply, to allow for stable operation of the Octopus.

A new measure that we implemented this year is to create a specific point of failure. As shown in Figure 7, all the electronics in the electronics tube are powered by an on-board 12V to 5V step-down regulator board, which we can manufacture quickly and easily.

In the event of a power failure, which may be caused by component failure or mishandling, the 12V to 5V regulator would be the component to malfunction, instead of the more complicated systems inside the electronics tube. And since these boards are easy to manufacture, we can simply replace it.

Figure 7: Power delivery system for the Octopus ROV

Mission Safety

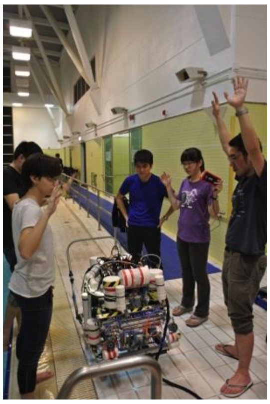


Figure 8: hands off the ROV

There are strict safety protocols that govern our use of electricity when using the ROV. Before the ROV is powered up, the voltage output from the tether and power regulators is checked before it is connected into the system. In order for power to be connected to the ROV, everybody must have his or her hands off the ROV.

Before every water test, our members follow a rigorous safety check list (shown below), making sure that not only the well beings of others are protected, but also to ensure that the machine will run optimally.

Safety Checklist

1) Check for physical signs of damage to the Octopus.
2) Check for any untighten screws or mechanical systems installed.
3) Ensure that there is dry silica gel in the electronics tube.
4) Ensure all connections on the electronics tube end plate are sealed tightly.
5) Ensure all waterproof connections have O-rings and are sealed tightly.
6) Close and seal the electronics tube.
7) Connect the tether to the shore side computer and 48V power supply.
8) Check that the voltage on the Octopus side of the tether is 48V.
9) Check that the voltage output of the 48-12V and 48-5V regulators are 12V and 5V respectively.
10) Connect the shore side computer to the tether in software.
11) Start the Octopus camera system, and open the camera software on the shore computer.
12) Ensure the pneumatic air supply is connected to the Octopus, to prevent water leakage.
13) Test all the systems, including the thrusters and pneumatic actuators, on the poolside.

If all systems are checked, the Octopus is ready to be deployed.

Subsystem Designs

Approach

This year, we took a very incremental approach to the design of the ROV. The designs were borrowed heavily from the successful aspects of last year, and by refining the existing designs we are able to achieve better performance and efficiency. This means that we can focus more on creating a better platform to accomplish the mission tasks, instead of building the platform from scratch. This also meant that we could reduce the cost of the Octopus. By recycling components that could still be used from last year, such as the tether, air compressor, Xbox controller, etc., we could reduce the cost of the Octopus, as well as save time, as we do not need to procure and/or build these components, and can therefore get straight to improving and implementing the new designs.

System Integration Diagram

The diagram below shows the system integration of the Octopus. The main power supply is equipped with a 40A fuse and the pressure regulator.

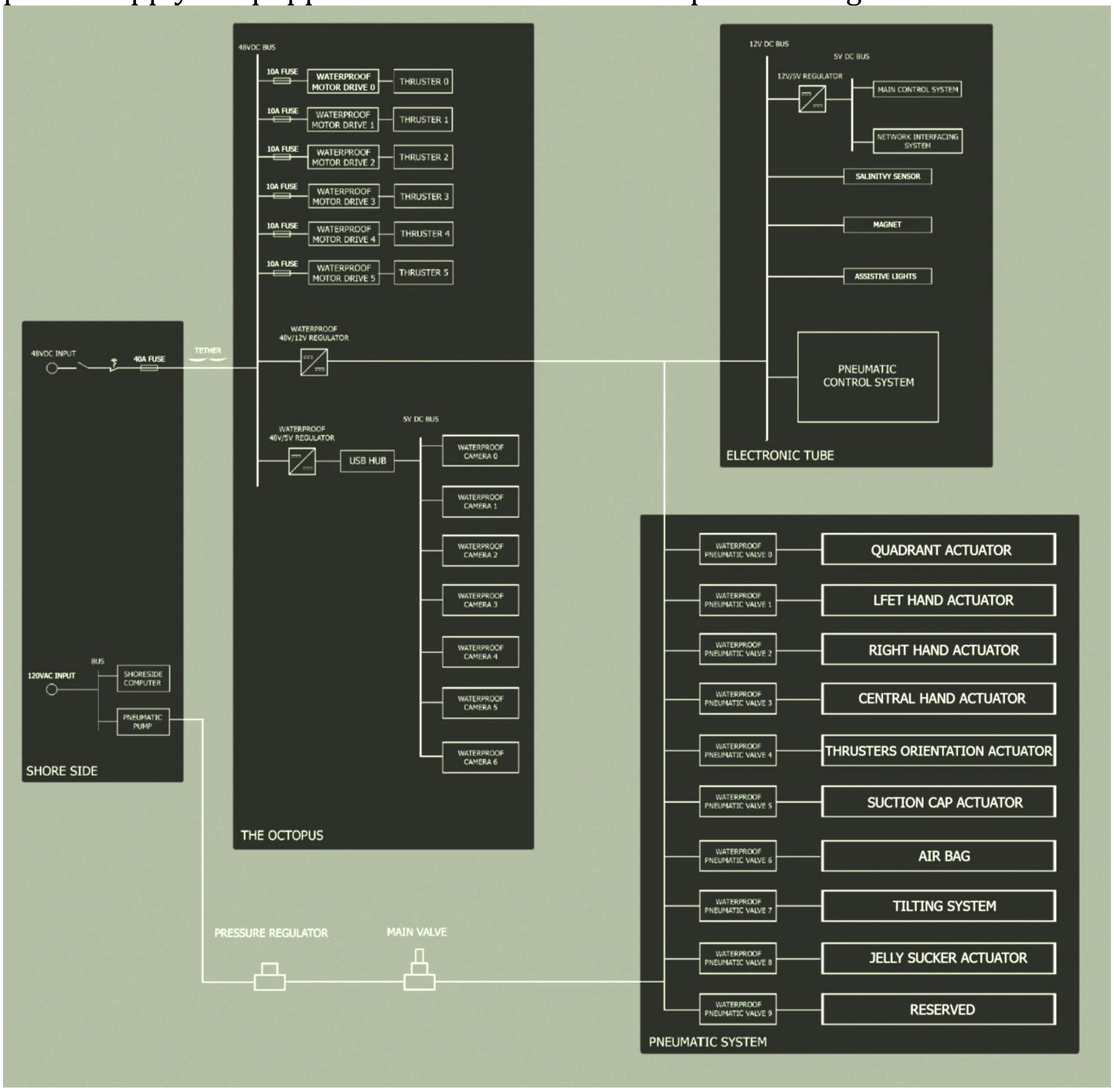


Figure 9: System Integration Diagram for the Octopus

Mechanical Subsystems

The table and the figure below show the Octopus tools and the position installed on ROV. The tools are specially designed in order to achieve better performance and efficiency.

Tool Label in Figure 10	Tool Name	Tasks Performance
A	**Quadrant**	• Platform for standing when focusing on targets • Count the mussels • Help open the cargo container
B	**Right Hand**	• Pick up plastic bottle
C	**Left Hand**	• Pick up glass bottle
D	**Jelly Sucker**	• Pick up agar sample
E	**Lift Bag**	• Provide additional lift for anchor
F	**Central Hand**	• Move the sensor strings around • Open the cargo container • Move the rope debris
G	**Disk Hand**	• Pick up the disk in the ship wreck
H	**Super electro-magnet**	• Pick up and transport the iron anchor

Table 5: Tables of Octopus tools and intended tasks.

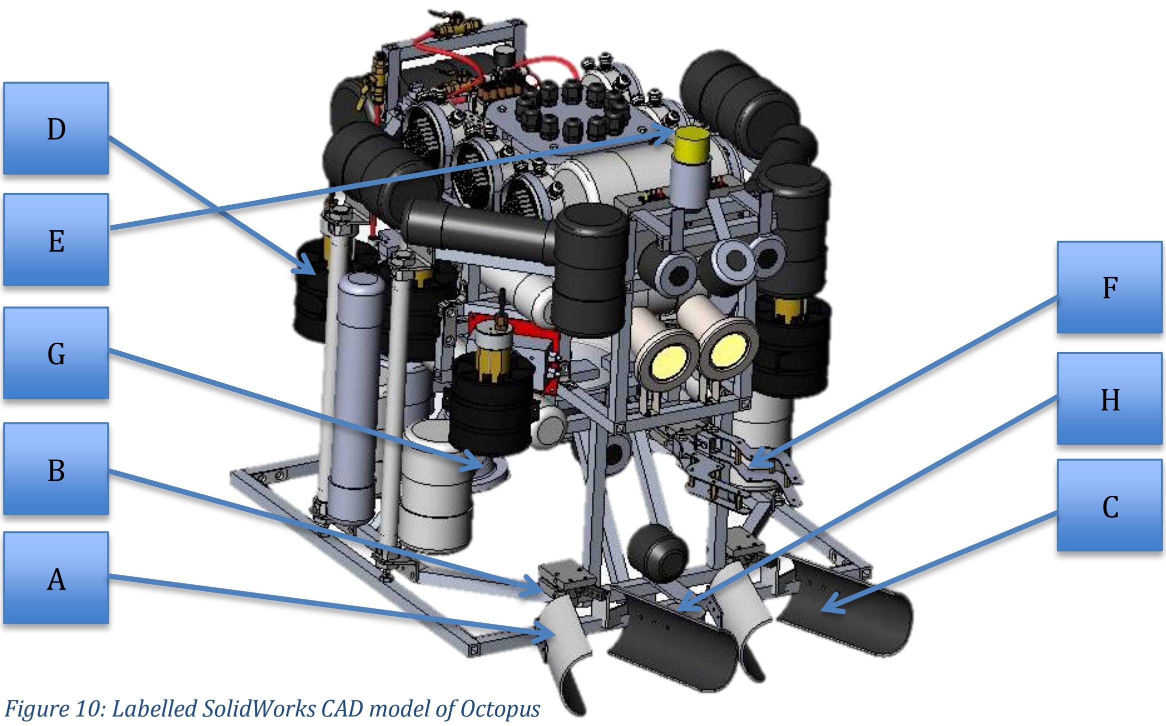


Figure 10: Labelled SolidWorks CAD model of Octopus

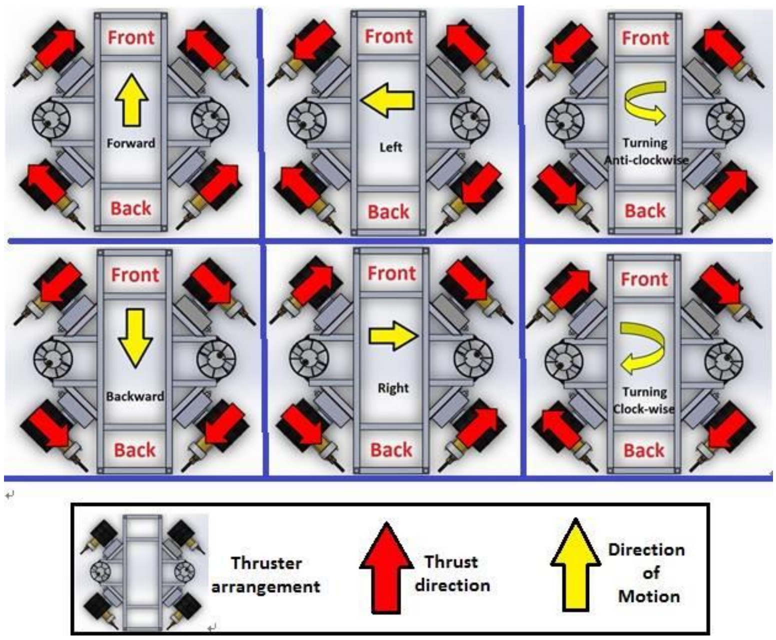


Figure 11: Explanation of the Octopus' propulsion system

Propulsion

The key mechanical system for any ROV is the propulsion system, as without it close to no tasks can be carried out. The Octopus is powered by 6 motors, which are rated at 250 Watts when using 12V. After multiple experiments, which are laid out later, we have determined that a 55 degree blade will give us the greatest amount of propulsion (up to 13 Newtons of force each) (refer to Blade Design in Troubleshooting Technique, Page 17), four of them are arranged at an angle of 45 degrees to the x-axis. These are in charge of going forwards, backwards, drifting and turning. They are connected to a rotational pneumatic enabling them to switch between horizontal and vertical position. This will be crucial when lifting the heavy anchor. Two motors are fixed in a vertical position. Figure 11 illustrates how we achieve different movements. It is important to have a machine which can move in so many ways, in order to help carry out the tasks. For example the focusing on the targets requires careful positioning, and since the shipwreck is very small, accurate movements are crucial.

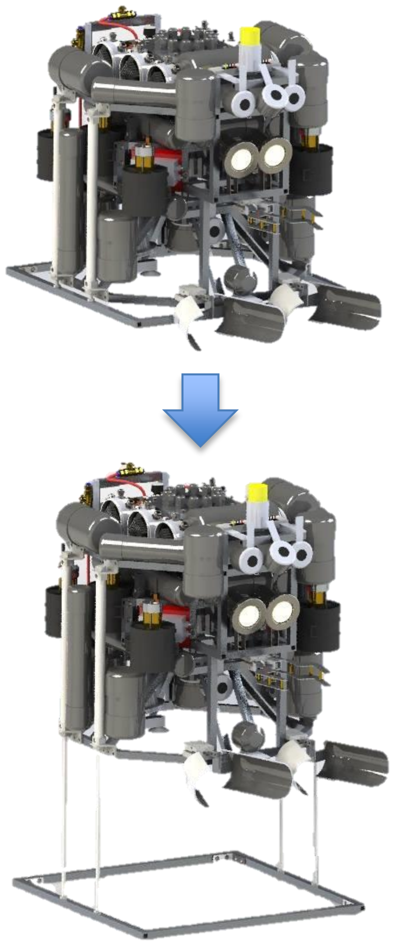


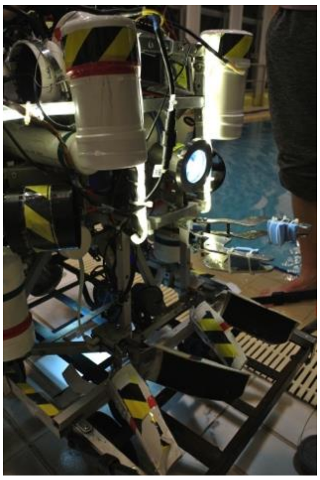
Figure 12: SolidWorks CAD Model of the Quadrant System before lowering (up) and after lowering (bottom)

Quadrant

This is a multi-purpose solution. As shown in Figure 12, we use a set of four pneumatics to extend the 50cm x 50cm frame. This system is created in line with our main focus of being as compact as possible and we don't need to bring extra payload tools. By using the compulsory quadrant to carry out multiple tasks we do not only reduce on space required for actuators but we also make our machine lighter and with fewer areas of possible problems. By having a lighter robot, to move through the water and hence can improve our mission time. The quadrant is used for adjusting the height of the Octopus during the focusing of the targets and counting the sea mussels.

Buoyancy System

Since the mission may need to be carried on a slope of up to 40 degrees the Octopus needs to be able to adapt to that. We have installed adjustable buoyancy tubes at the front and the back of the Octopus, which we can control from the shore and hence helps us to carry out the missions efficiently. Furthermore, since we have to pick up a seven pound anchor we have installed an airbag, which can provide us with the additional lift needed, since the motors themselves are not able to provide enough thrust to lift it from the depth.



Manipulators

We have installed three manipulators in the front of the ROV. Two of them are in charge of picking up the bottles, and are made from half cylinder PVC pipe (Label B & C on Figure 10). Through testing we found out that the optimal angle of separation is 30 degrees. We also have a multi-purpose hand installed in the front (Label F on Figure 10), which is in charge of handling the sensor string, rope debris as well as the opening of the cargo. It is important to have all these tasks operated by one hand, as it reduces space needed, and also due to size limitations.

Figure 13: Front View of the ROV and the three manipulators designed by our mechanic team

Electronic Subsystems

The majority of the electronics are housed in the main electronics tube that is at the center of the ROV, including the microcontroller board, pneumatic controller board, and Raspberry Pi. However, given the size limitations of this year's ROV, and the complexity of the system, the electronics tube had to be quite small, so we developed many waterproof systems, which can be placed in a more optimum location of their job, reducing wiring space, and making a more efficient layout. This includes the motor drivers, cameras, and conductivity sensor.

Microcontroller & Extension Boards

In 2013, we used the STM32F4 Discovery Board as our main controller platform. However, this discovery board was quite large, and had many extra features for our purposes. Using the same microcontroller, an STM32F407VG, we designed a new board that could fully support development on the platform, at a reduced size compared to the STM32F4 Discovery board. The core board, as it is so called, is then connected to an extension board, which is a much larger platform for the core board, which connects the output from the core boards, to the cabling which sends the signals out to the motor drivers. The extension board also provides features such as voltage regulation and connections to the motor drivers and pneumatic actuators, and protection for the core board, through the use of logic buffer chips.

Figure 14: The Octopus's control unit, with core board, extension board, and regulator board designed by our hardware team

Using this approach, we are able to incrementally update and test the software without having to disassemble the Octopus; all we have to do is replace the core board with an updated version. Similarly, to implement more features, we just need to design a new extension board, which has the features, without having to design the microcontroller section, which is a lot more complicated and time consuming. This makes the electronics design modular and easy to maintain.

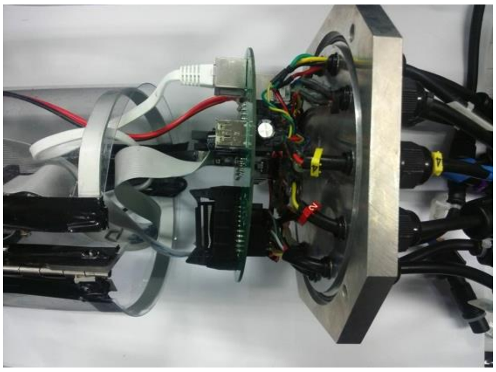


Figure 15: Wired up Interface Board

Interface Board

After developing the main electronics platform, we needed to find a way to interface them to the external systems. Previously, we used wires straight from the outside through a waterproofing end plate. However, this lead to a wiring mess, as there were over a dozen cables, that each needed to be individually wired. In an effort to combat this problem, we developed the system known as the interface board. The interface board serves as a sort of bottleneck for the cabling, as seen in Figure 15. On one side, you have many cables coming from the external systems. Some of the cables are grouped into a signal connection, such as the motor driver signals, or the pneumatic signals. We can then make a short cable run, using ribbon cables, to the electronics tube.

This resulted in a lot of improvements for the Octopus. It made maintenance a lot easier, as there were less cable to connect and disconnected when removing the electronics tube. It also added a certain level of dummy proofing to the electronics tube, as the ribbon cables can only be connected in a certain way, which ensures that each component is mapped to the correct connection, which therefore speeds up debugging, since we know that the component is connected correctly, and can focus on other areas.

Motor Drivers

The driver developed last year was housed inside an electronics tube cutting them off from any air circulation causing them to overheat. As a result, we had to limit the total power output of the drivers to 25% to keep them alive. This meant that last year's ROV did not have as much power as we would have liked.

Figure 16: Waterproofed motor driver

The solution to this problem was to create a waterproof motor driver, shown in Figure 16, taking advantage of the water to remove the excess heat. Using thermally conductive, but electrically insulating silicone, we attached a heat sink to the MOSFETs. Then we encased the motor drivers in epoxy, leaving only the heat sink exposed. This allows the excess heat to be conducted by the heat sink into the surrounding water, keeping the motor drivers within operating temperatures.

	2013 ROV motor driver	2014 Waterproofed Motor Driver
Power Limitation	25% due to overheating	70% due to motor limitations
Breakdown Frequency	*1-2 drivers every water testing due to overheating*	*Less than 1 driver every 4 water testing's due to extreme circumstances*

Table 6: Table of specifications of motor drivers

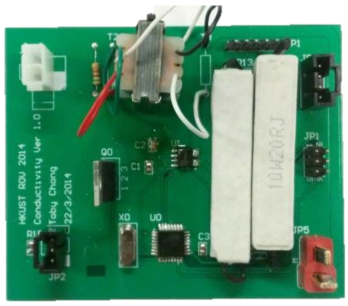


Figure 17: conductivity sensor

Conductivity Sensor

The mission tasks in the competition required measuring the conductivity of a groundwater sample, which we built a sensor to take readings in order to accomplish this mission.

To do this, we built a system around the Arduino platform, using the two probe technique (Webster and Eren). Using an ATMega328p, we generate a 1kHz PWM signal, which passes through Power MOSFET to amplify it to 12V. The square wave is then sent through a transformer to the probe, which is inserted to the saltwater. The resistance of the water is proportional to the salinity and temperature. Hence, the resistance across the transformer will vary with different salinity and temperature. Given a constant voltage supply, the current flow in the main circuit will change according to the aforementioned variables, and is measured with ACS712 current sensor. The output is combined the reading from the temperature probe, the conductivity is calculated and send back to the STM32F407VG MCU through UART, which can then be sent to the shore computer.

Software Subsystems

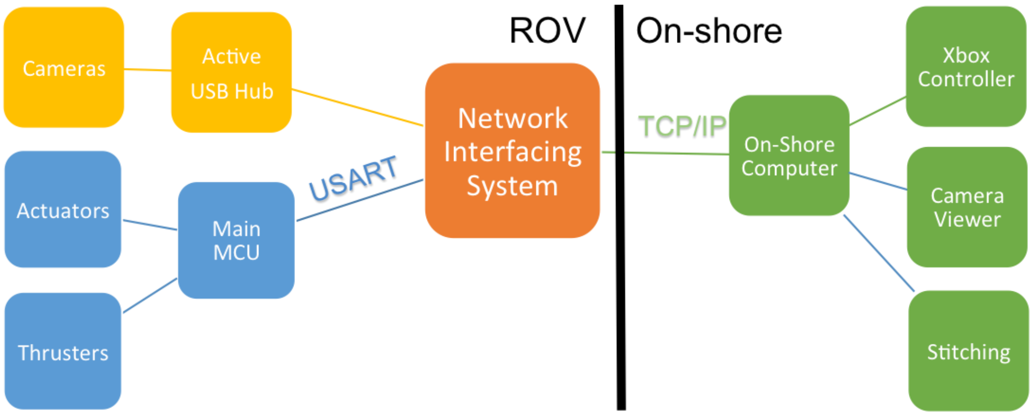


Figure 18: Software subsystem architecture

The overall software structure is comprised of three subsystems, shown in Figure 18. The shore side operation is done mostly by an on-shore computer, which provides the control software, camera software, and stitching software. The ROV side of the operation is done in two stages. The first stage is a router, which runs the camera streaming software, and the microcontroller interface, which passes control commands to the microcontroller, which then processes it.

Network Interfacing System

The network interfacing system (NIS) is the middleware between the Shore side and the ROV side systems, allowing the two systems to talk to each other over one Ethernet cable. The NIS is built using a Raspberry Pi running OpenWRT, which we chose because it offered better speed and stability to other operating systems.

The NIS runs two different pieces of software, one is 'ser2net', which translates commands between the hardware UART port, and a TCP socket on port 1019, which allows us to communicate with the main microcontroller from the shore computer. The second software is 'mjpg-streamer', which converts the USB webcam streams to a network video stream, which we can then view on the shore. We chose to use USB webcams over AV cameras because it allows us to have better quality video, and well as increased flexibility, as it can be easily scaled and adapted to situations, through enabling and disabling different streaming instances.

Main Microcontroller

The Octopus's microcontroller, the STM32F407 is the most crucial part of the whole system. The microcontroller is responsible for controlling the thrusters and actuators, which are the two key control systems that are needed for the successful operation of the Octopus. Therefore, the code needs to be stable and reliable. The code also needs to be fast, as quick reaction times allow the driver to accomplish his tasks faster.

Therefore, an intelligent command queue is implemented, which buffers received commands from the shore, making sure every command will be processed. The received commands are processed by a task scheduler who allocates a reasonable CPU time for incoming commands. This means that we can ensure that all commands are processed, but in a quick and efficient manner, which translates to a stable and quick Octopus.

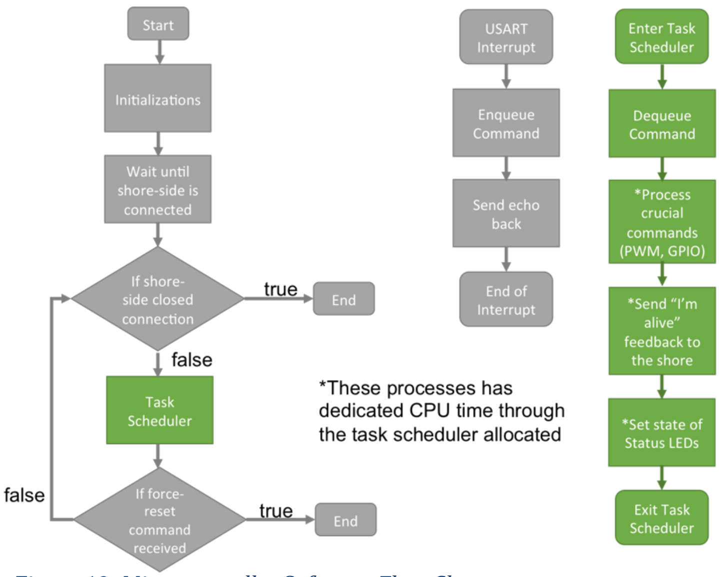


Figure 19: Microcontroller Software Flow Chart

We utilize a custom control protocol that we define, because it allows us to have a more efficient control system. This is because we only need to provision as many resources as we need, and therefore do not get weighed down with excessive commands that are never fully utilized, which consume both bandwidth and time.

On Shore Computer

The on shore computer is responsible for all the shore side tasks, which include controlling the ROV, accessing the camera feeds, stitching the photos together for the photomosaic task, and processing the stereo-camera images as part of the distance measurement task.

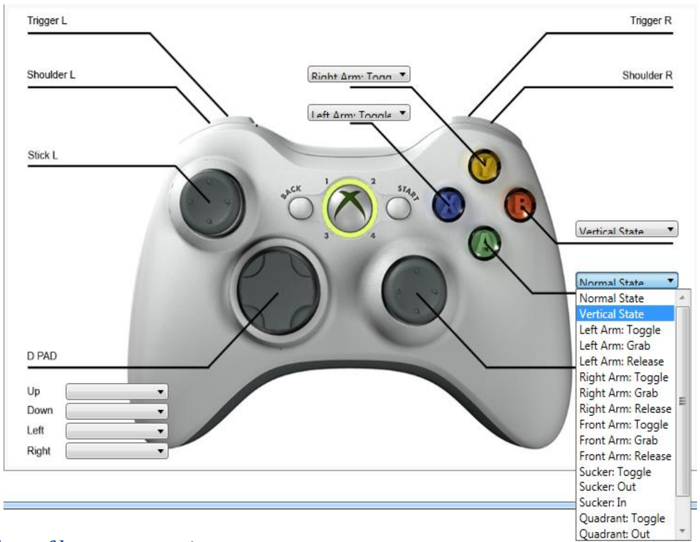


Figure 20: Screenshot of button mapping system

For controlling the ROV, Epoxsea Inc. has developed their own software in C#, based on Visual Studio, and the XNA framework provided by Microsoft. These frameworks allow us to develop our software very quickly, with full support for the Xbox controller. One of the key features implemented is the inclusion of driver profiles. These are files that can map the Octopus's functions to different buttons on the Xbox controller, as seen in Figure 20. The button mapping can be done on the fly. This allows the driver to fine tune their layout, so that they can accomplish the mission tasks faster, without affecting the other's drivers controls.

The thrusters will have different performances, due to variations in the motors and the motor drivers, some will be more powerful than others, which makes it harder to control. To solve this, we created a tuning system, where we can balance the motors dynamically, assigning more power to the front or back, or the left or right, in order to create a more controllable ROV, which can be seen in Figure 21.

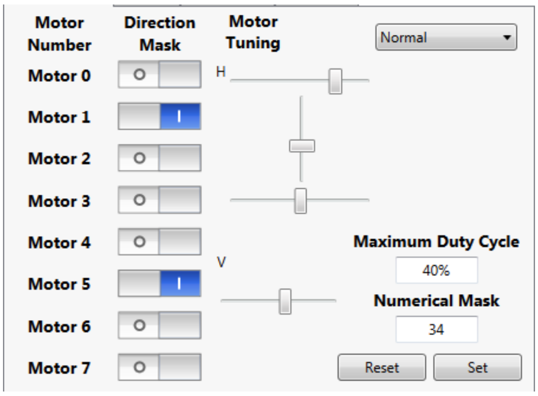


Figure 21: motor tuning system

Camera Stitching

One of the tasks will involve creating a photomosaic. Epoxsea Inc. decided that it is better to rely on the open-source software Hugin to accomplish this task. We chose this task because of two reasons. Firstly, since the software is open-sourced, there is a large community of developers that contribute to the software, that ensure that it is stable and well suited for the task. Secondly, writing our own implementation that would require a lot of adaption to the different variables, such as lighting and visibility, which could compromise our ability to achieve the task effectively.

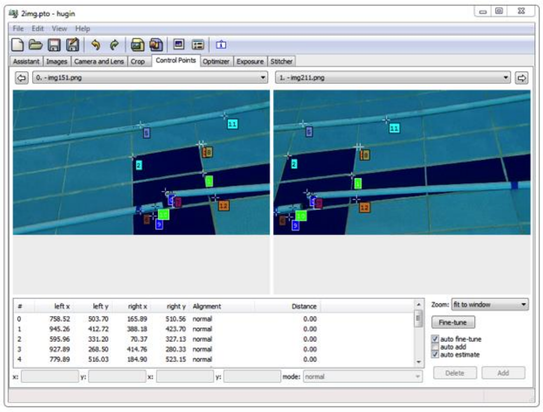


Figure 22: The photomosaic software

Stereovision

The mission required us to get the three dimensions of the shipwreck, length, width, and height. Since all the missions have to be done in the 15 minute time frame, we choose to utilize the fastest technique we could use, to free up more time to do the more challenging mission tasks. However, it is crucial that this task is also done correctly, since there are a lot of mission points for it.

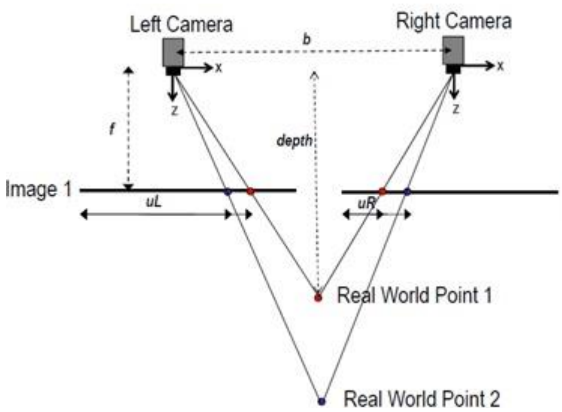


Figure 23: Description of the triangulation process of stereo camera system (Source: http://www.depthbiomechanics.co.uk/?p=102)

Epoxsea Inc. chose to use a custom-made stereovision system to accomplish this task, since stereovision can give a very accurate result, while being very fast. This is done by using two separate cameras on the Octopus. Similar to human eyes, the stereovision software can perceive small changes in size and angle, which is the mathematically solved for depth information, which can then be used to calculate the distance between two points of the image.

It is crucial to calibrate the cameras accurately, as parameters such as focal length and zoom will project the real-world coordinates differently to the image plane. To do so, Epoxsea Inc. use the OpenCV library and a common calibration approach (Bradski and Kaehler 370). During the calibration process, we define the relationship between the two cameras with a rotation and a translation matrix. We can then use these matrices to reverse engineer the real-world coordinates of the objects in the images, using triangulation, the technique shown in Figure 23.

Mission Helper

During trial runs and testing of the Octopus, we found that it would be very beneficial for the drivers to develop a mission helper application to reduce their workload. Our mission helper software can keep track of remaining mission time, mission task status and order, and also identifying the shipwreck based on the 4 parameters. We also incorporated some features to aid in the driver training, allowing them to see how much time they use for mission task, which can then be used to develop a better and more flexible mission plan.

We designed the mission helper software as a web application, using HTML5, JavaScript, jQuery, and Bootstrap. This allows us to have a very flexible application, which can easily be used on desktops, tablets, or phones with no change in code. Designing the system as a web app also allows us to quickly and easily deploy the software, since it does not need to be compiled or installed before it can be used. The mission helper can also be used on smartphones or tablets which provides flexibility to monitor the mission status.

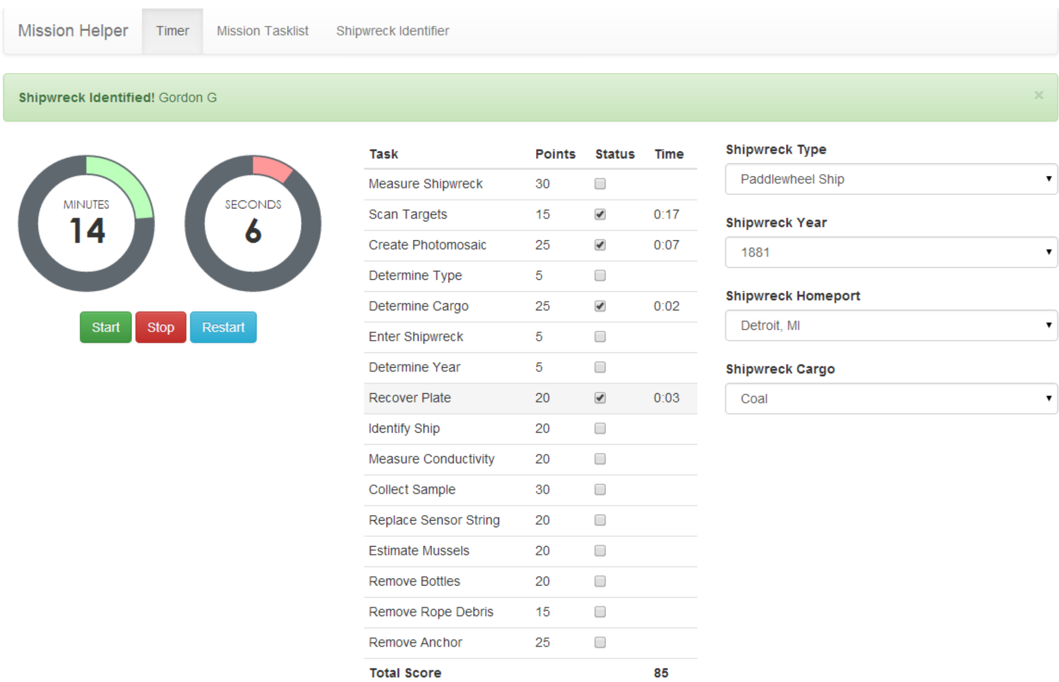


Figure 24: Screenshot of the Mission Helper application.

Troubleshooting Techniques

Blade Design

Since we developed our own waterproof thrusters for the Octopus, seen in Figure 26, we also had to design blades to fit the motor, seen in Figure 25, in order to achieve maximum efficiency and lower the cost. Due to the size constraints we had to find which angle gives us the most thrust.

Figure 25: Collection of testing blades (Different Angle)

Figure 26: Assembled thruster

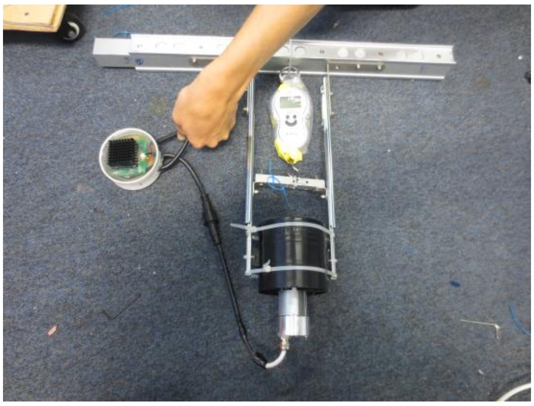


Figure 27: Testing apparatus designed by Jacky

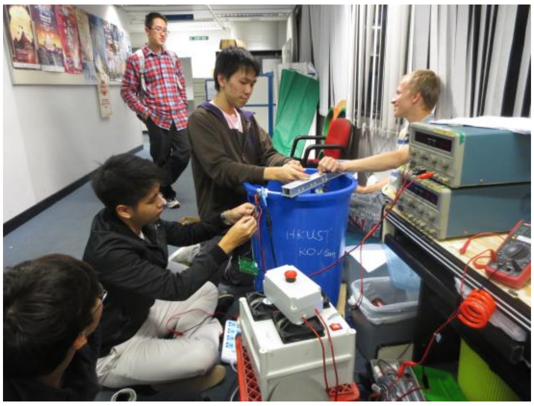


Figure 28: Mech. Team Thruster testing setup

Our testing apparatus consists of a 48V power supply, an STM32F4 Discovery board to provide a PWM signal, a waterproofed motor driver to control the motor, and an assembled thruster with the test blades.

The programmer will first set the PWM value to a percentage that we desired. For our purposes, we used the range of 20% to 70% at 10% increments. We chose this range when the PWM value was less than 20%, the motors could not overcome the static friction of the waterproofing, and a PWM value over 70% would exceed the motor's voltage rating of 30V. After applying the PWM signal, the force that is read from the force meter on the testing apparatus is read and recorded.

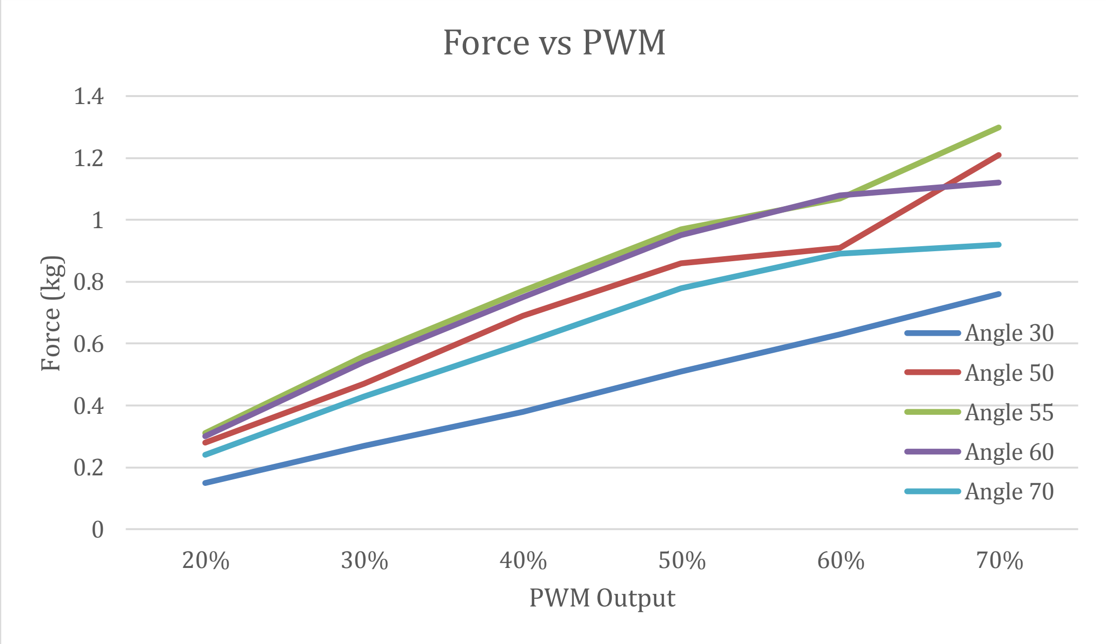


Figure 29: Force vs PWM graph of the blade angle testing

From the data, shown in Figure 29, it is determined that the angle that produced the most force was 55 degrees. From that, then needed to determine whether it was suitable for use in both a push and pull configuration.

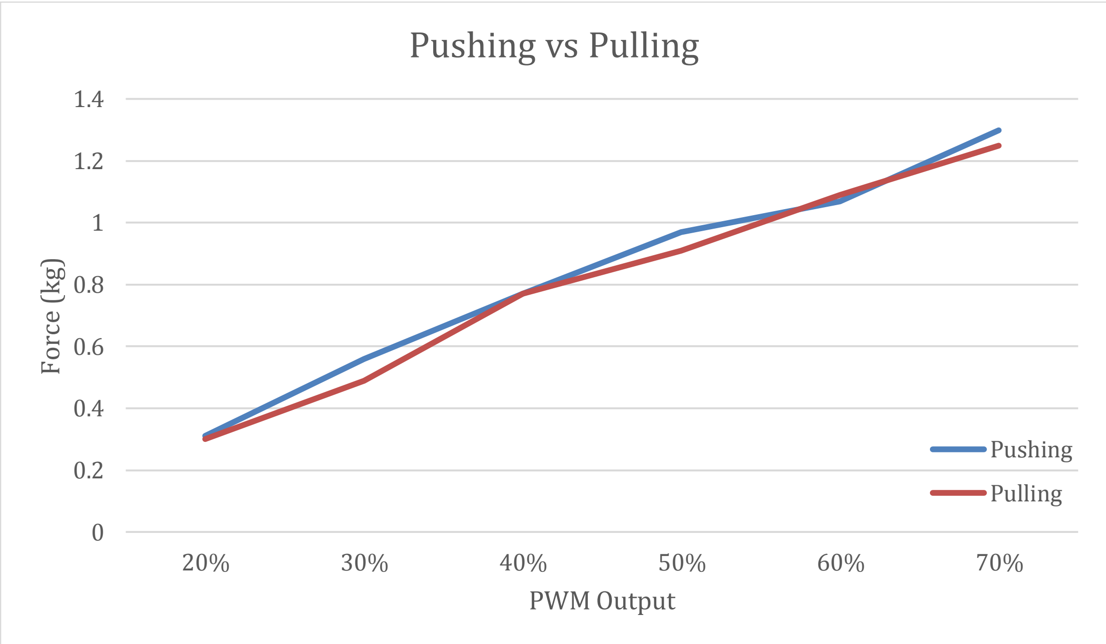


Figure 30: Force vs PWM graph of the push vs pull testing

The data in Figure 30 shows that the thruster is reasonably matched in both directions, and that it is suitable for use on the Octopus. It is also evident that the orientation of the thruster does not matter in the design of the Octopus, since the thruster operates at the same efficiency in both directions.

Core Board Status LED

There may be a chance to encounter the problem that we do not know in which state the microcontroller is in (e.g. idle, wait for command, connected, disconnected etc.), we may lost a significant amount of time while attempting to reproduce the problem. Therefore, we redesigned our core board with status LEDs which can give us instant feedback for debugging while keeping the same form factor, allowing it to function as a drop in replacement.

System Debugging

After developing the Octopus, we have implemented a troubleshooting platform, which we can use to narrow down the problem, until it is found and solved. As seen in Figure 31, we can generally attribute the majority of the Octopus's problems to faulty/improper connections, which can be fixed quite easily. However, if by the end of the flowchart, we cannot determine the problem, then we can narrow the source of the problems to the subsystems that are problematic. For example, if the thrusters are not turning, but the debugging checklist is verified, we then know that the problem is with the motor drivers, and we can therefore test that subsystem individually.

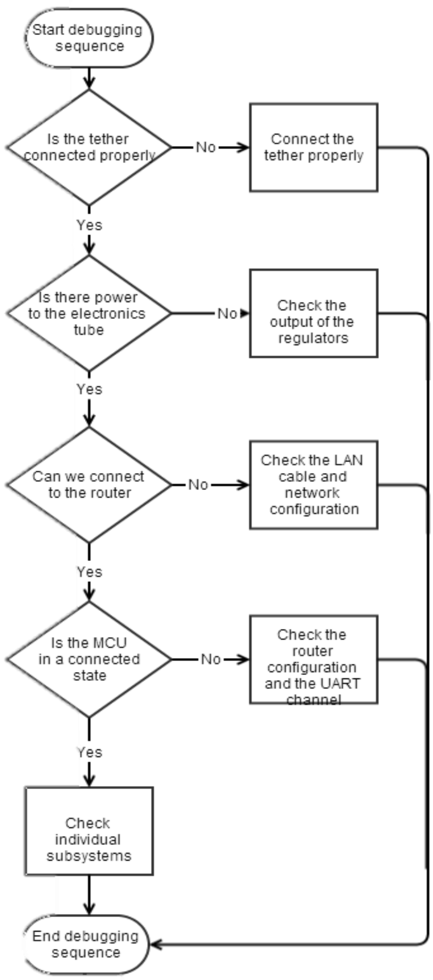


Figure 31: Debugging flowchart for the Octopus

Challenges

Non-technical Challenges

Initially the biggest problem that we faced was communication. Our team is very international, featuring members from across the world. In the long run, this turns out to be very advantageous, since the different people and mindsets create better ideas. However, in the beginning, communication was not good, we all used different terms to describe the same thing, e.g. what one person would call multimeter, and another would call a DMM, which lead to confusion. Also, many members had a different first language, which they sometimes used to communicate to others, but at the cost of excluding other people. We set up rules for communication and using social media as communication platforms. After some time, this issue began to fade, as we got to know each other. The working environment is amazing. We enjoy work together and play together!


Figure 32: Dance Move Together!!

Technical Challenges

Compared to last year, from the beginning we had to think about the size of our robot. This lead to the designing process to take longer than last year. Furthermore since unlike last year, where everyone designed one part of the system, and then it was put together, we designed the entire system together. This meant a lot more negotiation and fine tuning. It was a very time consuming process, which meant we had less time to manufacture the actual robot.

Figure 33: Testing Octopus ROV in swimming pool

Wiring also proves to be a severe challenge for the Octopus, since we have found that they are the most likely point of failure, and the most time consuming aspect. There have been occasions where faulty wiring has caused malfunctions in the Octopus, including a few severe malfunctions that rendered the Octopus unusable, and in need of serious maintenance. Hence we develop a safety protocol before every missions to ensure the machine is in perfect state.

Also, since we are using a lot more waterproof systems, there is as much greater emphasis on testing and refinement, since after waterproofing; the electronic systems cannot be altered, so it becomes essential that they are suitable for use from the beginning.

Creating the camera system for the Octopus was also a great technical challenge. The Octopus has 7 cameras, which all need to be processed and sent to the surface for viewing and analysis. To do this, we need to have a powerful processor that can convert the raw data from 7 cameras to streams for relaying to the surface. This would result in a lot of experimentation with lots of different embedded systems, including the TP-MR3020 router, the Raspberry Pi, and the BeagleBone Black systems, as well as different parameters for the streaming software 'mjpg-streamer'. After a lot of development, we created a stable system using the Raspberry Pi, which is more powerful than the TP-MR3020. Finally we have successfully created a stable network interfacing system for the Octopus.

Lessons Learnt

The most important we learnt during the development of the Octopus would be the importance of dummy proofing the system. Initially, the Octopus was not very maintenance friendly. There were many cables that could easily be misconnected, and there was no easy way to debug any possible problems. After a while, we learnt that there are times when this is suitable, but in a rushed or overworked situation, it is easy for one of them to be overlooked, which ends up causing a malfunction in the Octopus, even a serious one.

We implemented a lot of systems after realizing this. All internal cables were made locking, so they cannot become accidentally disconnected during the transport or operation of the ROV. All external cables were made keyed, so for example, only motor drivers can be connected to their outputs, the 48V power cannot be connected to the 12V/5V cable, making the system more dummy proof.

We also added switches to help with the debugging, such as Tx-Rx line swappers, which makes debugging and wiring a lot easier.

Interpersonal Skills

We also learn that interpersonal communication is the key to success to any team. In the beginning it was difficult for all members to communicate with each other due to language barriers. As we got to know each other more, this barrier was removed. For future years, we know that in the beginning it is very crucial to spend time with each other, like lunch gathering and hiking together, to figure out the best way to communicate with each other.

Since many of Epoxea Inc.'s members were new this year, they had to spend a good amount with the old members to make sure that they have sufficient knowledge to build the Octopus. Furthermore, one of the members has built a knowledge database server, to make sure that future members can easily find out about things, in which others have conducted experiments or research.

Future Improvements

Feedback System

The majority of the Octopus uses an open loop control system, which means that we have a high tolerance for error, as we have no way of ensuring that the commands are being parsed correctly. Implementing a feedback system would be a huge advantage for future ROV's.

One feedback system is to add the microcontroller feedback to the shore, so we can see whether the microcontroller is receiving and parsing the commands correctly. This would aid the debugging process, as we can use the feedback to determine possible problems. If the feedback does not match the sent commands, we can narrow down our focus to the communication system, whereas if the feedback is correct, we can narrow down the focus to the downstream subsystems.

Another system would be to add current sensors to the motor drivers, so we can see how much power the motors are consuming. We can then use these with control algorithms to keep the motors at a more stable control point, and therefore create a much more stable robot, without having to tune the system manually, or account for it while driving the ROV.

Odometry

Automating the control systems of the ROV would make controlling the system much more simple. Using multiple sensor methods, such as inertial measurement units, stereovision, and sonar, we can determine the location of the ROV in the pool, and build a relaxed stability system, where the driver tells the ROV to go in a certain direction, and the ROV calculates which motors to turn, and at what speed, to achieve this direction. We would also like automating some of the stability tasks that would require the pilot's attention. This would reduce the load on the pilots. With the system in place, we can achieve precise positioning control for the ROV.

Reflections

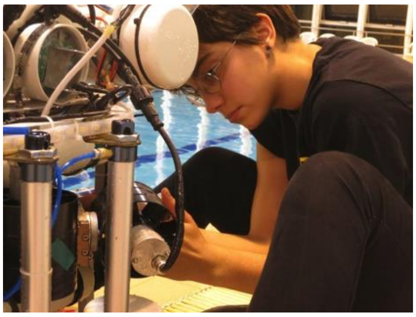


Figure 34: Rayan ARMANI

"Building the ROV helped me develop and use many skills much faster than any other way I can think of, not only in the mechanical design and building but also some basics electronics that I learnt from the other team members. I really enjoy the challenge of making an ROV together with them and really look forward to the competition!" (Rayan ARMANI, freshman)


Figure 35: Christopher SOEBRATA

"Working with the ROV team 2014 has been really exciting for me. Having members from various countries enhances more communications between one another. The working environment is really good since we are supporting each other in order to pursue our main goal: Win the International Competition! Having previous year experience also help me a lot in preparing this year's ROV. This past two years has been very fruitful for my experience on industry-related works, providing necessary set of skills for my future career." (Christopher SOEBRATA, return member)

"Having the possibility to join the HKUST ROV team is especially special to me, as I am a business student. This competition has very high meaning to me, as it is the first time for me to possibly compete on an international level. Working with people who all have different, is very good, as there is always something new, which can be learnt" (Johannes Thomas Maria JAEGER, freshman)

Figure 36: Johannes Thomas Maria JAEGER

Corporate Social Responsibility


Figure 37: Picture of one of the ROV workshops

Epoxsea Inc. has helped to conduct three workshops this year. We lined up industrial parties (RS Components Ltd. & Oceanway Corporation Ltd.) to sponsor components for the workshops. These were to help other local and international participants of the MATE ROV competition building and designing their robot. We aim to upgrade and improve secondary school students' skillsets in building their own ROV through the workshops. As a result, we are happy to know that over 40% of the regional ranger teams applied the technology we taught in the workshop in their ROV design. We also provide technical consultation services to all the teams participated in Hong Kong Regional Competitions.

Figure 38: Underwater Robot Workshop for Visually impaired students in Ebenezer School & Home for the Visually Impaired

Besides organizing workshops, Epoxsea Inc. has applied the ROV technology into the inclusion activity. This year, we convert the ROV technologies into an appropriate format for the children from School Ebenezer School & Home for the Visually Impaired. In March 2014, we conducted an additional workshop to teach them how to build their ROVs. Finally, twelve visual impaired students formed two teams to join the Hong Kong regional scout class competition. With a keen competition with ordinary students, these visual impaired children got the first-runner up. We really excited to see them enjoy in building their own robots and using our own engineering knowledge to serve the society.

The gratitude letter and comments from teams participated in the competition 2014 are listed below:

Oceanway Corporation Limited
Unit. 3, G/F., N0. 34, Tai Chung Hau Village, Sai Kung, Hong Kong(S.A.R.), P.R.C.
Tel: (852) 2791 5331 Fax: (852) 2792 5331

15th March 2014.

Ref: OCL/2014/I2837ql

The University of Science and Technology
Clear Water Bay
Kowloon
Hong Kong

Attn : Mr Eric Leung

Dear Eric,
Re: The Advanced Underwater ROV Workshop

I am writing to thank you and the HKUST Robotics Team for the help and support given at the Advanced Underwater ROV Workshop I held for the 2014 contestant teams during January.

Not only were you helping the Ranger teams understand the basic elements of sealing cameras and basic electronic troubleshooting, you also helped some of the competing Explorer teams achieve the same. These are the same Explorer teams that will meet you in the pool soon and compete against your ROV. Such action shows a healthy professionalism towards the ROV learning community.

I wish your ROV team well in the up and coming competition. I have no doubt that you will achieve a high score in all of the different parts of this year's HK Regional IET/Mate Underwater Competition.

Yours sincerely,

Paul Hodgson.
Director, the Oceanway Corporation Limited.

Figure 39: Letter of gratitude from Paul Hodgson, one of the Regional Organizing Committee members

Muhammad ZUHDI (Undergraduate Student, UTM, Malaysia Explorer team) Provide Very good program which can help participant in build their ROV as well as give the important reminder to the participant. HKUST team is very supportive.

Figure 40: Quote from member of the Malaysia UTM Explorer Team

Miss WONG (Mentor, Po Leung Kuk Ngan Po Ling College, Hong Kong Ranger team) Thank you for your sponsorship to this treasurable event. We learnt a lot and really enjoy ourselves in this competition. It is absolutely an unforgettable experience working on our ROV and participating in the workshops and competition.

Figure 41: Quote from mentor of the Hong Kong Ranger Team

Queenie YEUNG (Mentor, CMA Secondary School, Hong Kong Ranger team) Thank you for HKUST Robotics Team organizing the advance workshop for the all the participants. Especially for the junior student, these workshops help them to understand the structure and theory of ROV. We all enjoy the workshop. Also, we are looking forward to joining the similar workshop organized by HKUST Robotics Team. It is because those workshops can able to raise the secondary school student awareness and interest in technology.

Figure 42: Quote from mentor of the Hong Kong Ranger Team

Students (Ebenezer School & Home for the Visually Impaired, Hong Kong Scout team) Thank you HKUST ROV Team to teach us how to build the ROV. They give us great support and help. We learn basic ROV structure and equipment. Moreover, we can work as a team and build our own one. At here, I would like to say thank you once again to HKUST ROV Team.

Figure 43: Quote from the students of Ebenezer School & Home for the Visually Impaired

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HKUST School of Engineering – for providing the funds and laboratory spaces for Epoxsea Inc. to use.
HKUST Center for Global & Community Engagement (GCE) – co-operate to provide advance training workshop for Hong Kong ranger teams and also ROV building workshop for Ebenezer School & Home for the Visually Impaired.
HKUST Design and Manufacturing Services Facility (DMSF) – for providing technical support and suggestions to Epoxsea Inc.
HKUST Student Affairs Office (SAO) – for allowing us to use the swimming pool for the testing of the Octopus.
Professor Kam Tim WOO – our supervisor, whose guidance and advice helped us improve both our technical, and non-technical skills. We greatly appreciate his effort and support of our team in our endeavors.
Lok Ping LEUNG, Chun Yin LEUNG, and Sau Lak LAW – our mentors, whos guidance and technical advice proved to be invaluable while developing the Octopus.
MATE Center – for organizing the international competition, providing a platform for the growth of the entire community, and being the origins of the competition.
The Institution of Engineering and Technology, Hong Kong (IET HK) –for organizing the Hong Kong/Asia Regional of the MATE International ROV Competition 2014, and supporting the fundraising of the Hong Kong Teams.
RS Components Ltd– for providing in kind donations of electronic equipment and design software for electronics.
Dassault Systems – for providing ‘SolidWorks Student Edition’ CAD software for Epoxsea Inc.