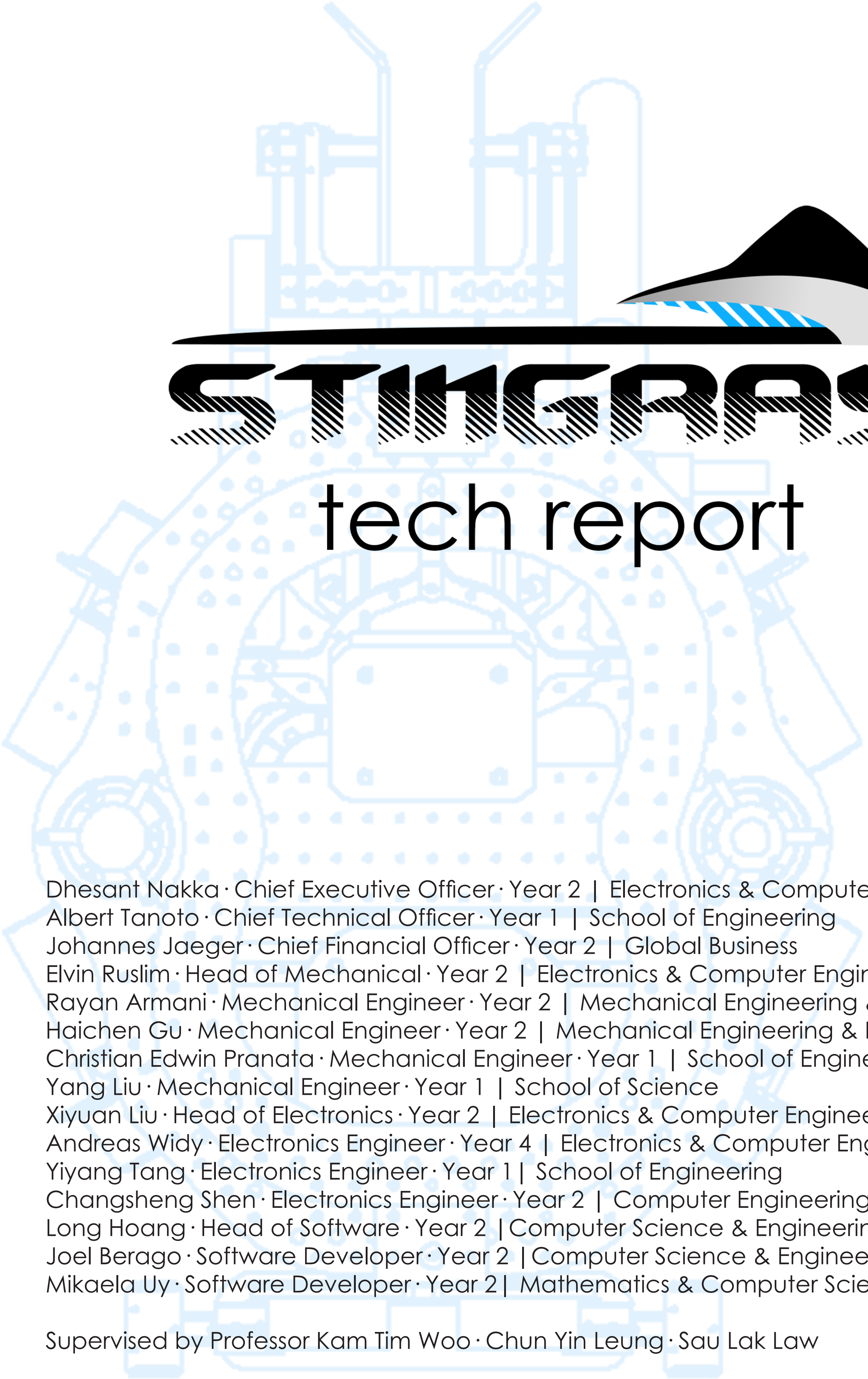
香港科技大學
THE HONG KONG UNIVERSITY OF
SCIENCE AND TECHNOLOGY

epoxsea



STINGRAY
tech report

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Abstract

This report illustrates the technical aspects of the Stingray, a ROV (Remotely Operated Vehicle) developed, designed and manufactured by Epoxsea Inc. The Stingray is a response to a request made by the Marine Advanced Technology Education Center for a ROV which can operate in various extreme environments, including conducting science under the ice, inspecting and repairing sub-sea pipelines, and producing and maintaining an offshore oilfield. The Stingray takes advantage of advanced and mature technologies such as pneumatic actuators, ATmega32M1 microcontroller series, ROS framework using Python and C++, CAN communication and brushless thrusters.

The Stingray has a tilted acrylic tube, which houses the main control system. To orientate itself in the water and to effectively carry out the missions, the Stingray is equipped with six wide-angled digital cameras. For propulsion, the Stingray features six high power brushless thrusters using a vectored thrust orientation.

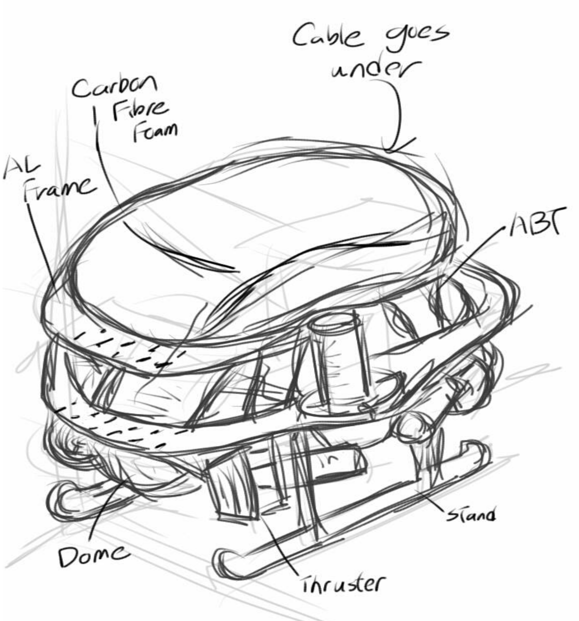


Figure 1: Concept drawing of the Stingray

One of the major improvements compared to last year's robot is the emphasis on being compact and modular. This is important in order to allow us to develop mission specific manipulators without having them implemented on all missions. Taking advantage of up-to-date technology, which is available on the market, and out of the box thinking, a team of diverse and creative engineers designed the Stingray, a ROV that is capable on meeting the requirement set forth by the MATE Centre.

Figure 2: Team photo from a training session
Top row (left to right): Elvin Ruslin, Yang Liu, Changsheng Shen, Xiyuan Liu, Andreas Widy, Dhesant Nakka, Rayan Armani, Mikaela Uy, Haichen Gu, Yiyang Tang
Bottom row: Johannes Jaeger, Joel Berago, Edwin Pranata, Long Hoang, Albert Tanoto

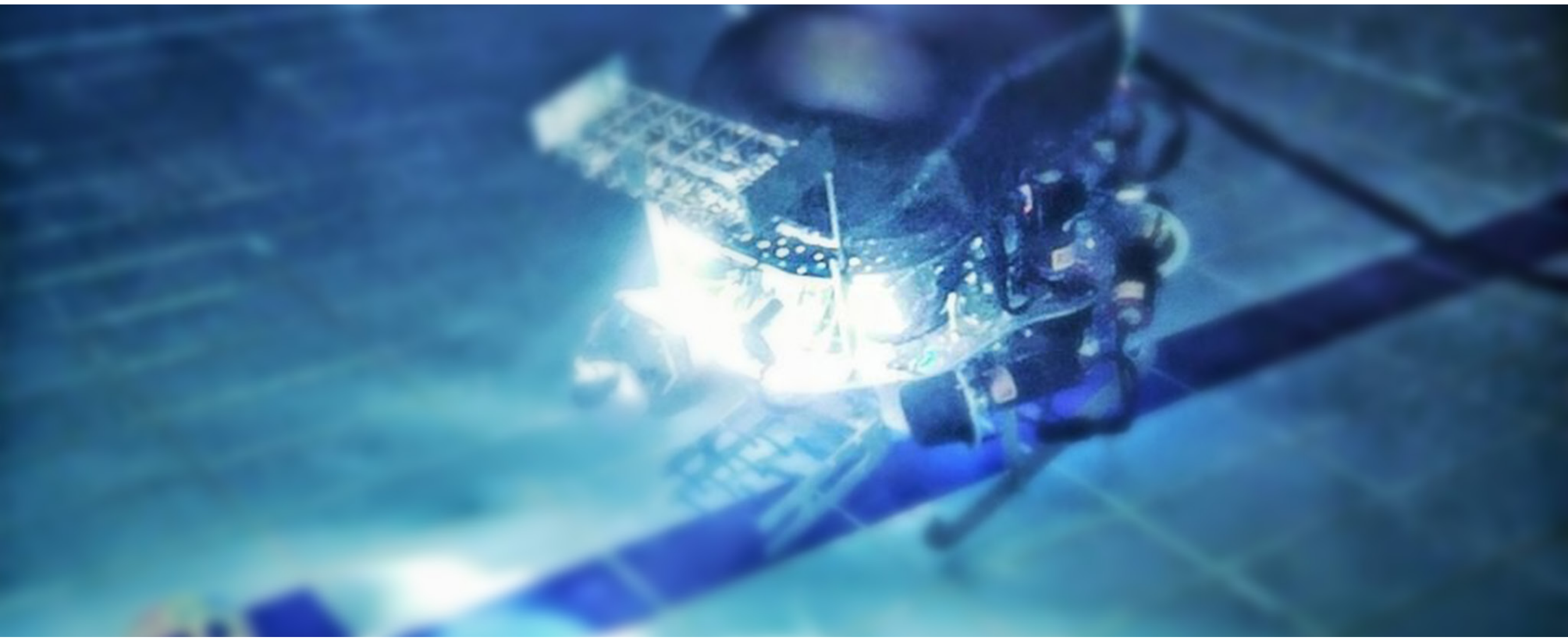


Figure 3: The Stingray underwater

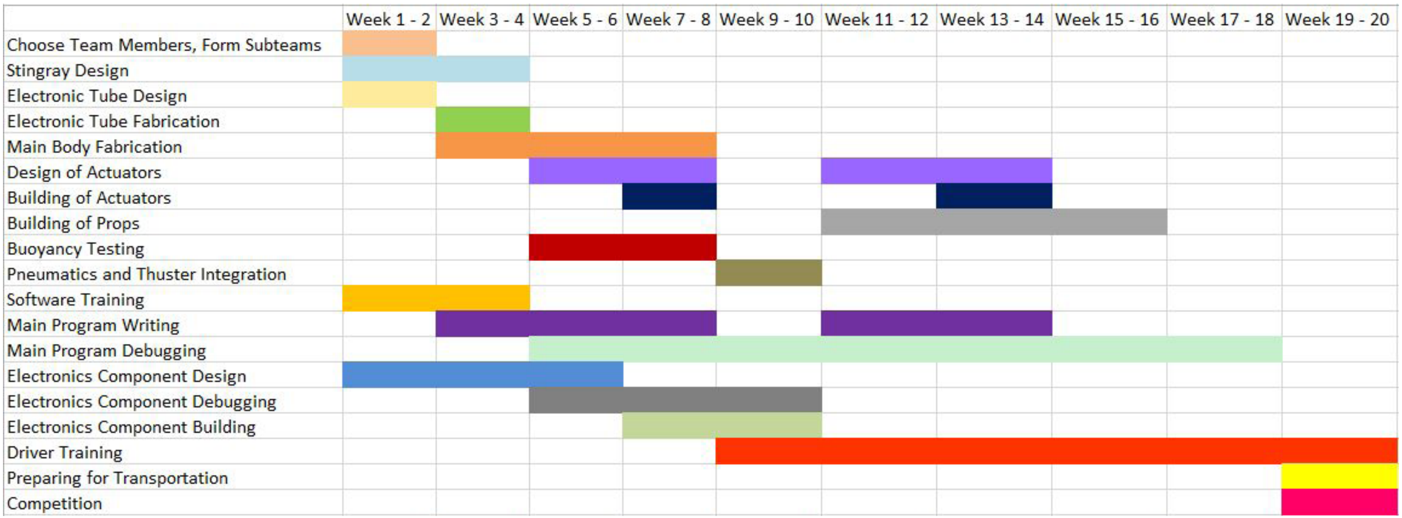
Table of Contents

Design Rationale

The Stingray was built by Epoxsea Inc. in response to the request for proposals issued by the MATE Center in 2015. The request specified that the product must be able to conduct scientific exploration under the ice, inspect and repair of subsea pipelines, and produce and maintain offshore oilfields. In response to these requirements, Epoxsea Inc. has decided to engineer the Stingray from scratch, implementing new features in all areas, mechanical, electronic and software. Some of the new features include designing a new, flexible framework that features multiple mounting options, creating custom made buoyancy floats, using brushless motors for better power and control, using the ROS framework (Robot Operating System), and implementing modular electronics using the Controller Area Network (CAN). This helped us remove many legacy components and creating a more stable machine. In order to finish the proposal on schedule, work started as early as late-2014. Figure 4 displays the development progress of the Stingray.

This is the second time that the MATE Center is requesting that multiple missions be carried out by one machine, which prompted the mechanical division of Epoxsea Inc. to take an entirely different design approach than before. By first considering the limitations of previous ROV's, we were able to identify different areas for improvement, which were improving the modularity of the ROV and making the ROV more compact. This resulted in the addition of copious mounting options, replaceable manipulators and more powerful thrusters to the Stingray. We designed multiple variations of the Stingray's frame using CAD software, which allowed us to test different designs without wasting time, resources, or material, helped us become an environmentally friendly company and also sped up the development. After the framework was designed, the focus then shifted to developing the mission specific manipulators, as well as experimenting and implementing new buoyancy systems.

The software and hardware divisions also set their sights onto improving the modularity of the Stingray. Microcontrollers were added to all the electronic components on the Stingray, which, using the CAN architecture, allows bidirectional communication between the control systems and the components, feedback data to ensure proper operation and a more modular system, as different components can be added and removed as necessary. The control software for the Stingray was also split into multiple independent modules, which communicate over the ROS framework. This allows an increase in development speed and more flexibility, as mission specific modules can be deactivated when needed to increase the speed of operation.



	Week 1 - 2	Week 3 - 4	Week 5 - 6	Week 7 - 8	Week 9 - 10	Week 11 - 12	Week 13 - 14	Week 15 - 16	Week 17 - 18	Week 19 - 20
Choose Team Members, Form Subteams	■									
Stingray Design	■	■								
Electronic Tube Design	■									
Electronic Tube Fabrication		■								
Main Body Fabrication		■	■	■						
Design of Actuators			■	■		■	■			
Building of Actuators				■			■			
Building of Props						■	■	■		
Buoyancy Testing			■	■						
Pneumatics and Thuster Integration					■					
Software Training	■	■								
Main Program Writing		■	■	■		■	■			
Main Program Debugging			■	■	■	■	■	■	■	
Electronics Component Design	■	■	■							
Electronics Component Debugging			■	■	■					
Electronics Component Building				■	■					
Driver Training					■	■	■	■	■	■
Preparing for Transportation										■
Competition										■

Figure 4: The build schedule for the Stingray

Budget Report

The following is the budget report for the development of the Stingray during 2014-2015. In total, the Stingray costs USD8,722.47 to develop, with USD46,087.36 in sponsorship.

Item No.	**Sponsor**	**Remarks**	**Price (HKD)**
1	HKUST School of Engineering	Finances for parts & travel	330,000.00
2	RS Components Ltd.	Electronic Components	4,289.00
3	Dassault Systems	SolidWorks Student Edition (20 Licenses)	23,275.20
		Sub Total	**357,564.20**
		Total Sponsorship in USD (1 USD = 7.7584 HKD)	**USD46,087.36**

Table 1: Table of sponsorship received by Epoxsea Inc. for the development of the Stingray

Item No.	**Item Name**	**Quantity**	**Price (RMB)**	**Price (HKD)**
1	Epoxy Resin	N/A		1,400.00
2	Acrylic Tubes	2		525.00
3	Air compressor (re-used)	1	475.00	
4	Aluminum Frame	1	5,000.00	
5	AV Cameras	4		720.00
6	Bilge Pump	1	100.00	
7	Brushless Speed Controllers	6	3,600.00	
8	Brushless Thrusters	6		28,000.00
9	Buoyancy Foam	1		50.00
10	Cable Ties	10 Packs		150.00
11	Camera Lens	6	138.00	
12	Manipulator Components	N/A		10,000.00
13	Odroid-XU3	1		1,500.00
14	Electronic Components & Boards	N/A	1,425.00	
15	Pneumatic Cylinder Mounts	18	45.92	
16	Pneumatic Cylinders	20	1,950.00	
17	Pneumatic Tubing	20m	200.00	
18	Power Connectors	10		560.00
19	Power Regulators	2	750.00	
20	Solenoid Valves	13	754.00	
21	Tether Cabling	1		4,000.00
22	Waterproof Lighting	2	50.00	
23	USB Cameras	6		654.00
24	USB Hubs	2		200.00
25	Valves, Pipe Fittings, & Pressure Regulators	N/A	515.00	
26	Waterproof Connectors & O-rings	45	222.50	
27	White Lithium Grease	2		500.00
28	Xbox 360 Controller (re-used)	1		329.00
		Sub Total	**15,225.42**	**48,588.00**
		Total Cost in USD (1 USD = 6.1896 RMB = 7.7584 HKD)		**USD8,722.47**

Table 2: Table of parts expenditure for the Stingray

Item No.	**Item Name**	**Remarks**	**Price (USD)**
1	Stingray parts	See Table 2	8,722.47
2	Stingray Transport	Freight costs	7,733.86
3	Team Travel & Logistics	Overseas travel expenses for 13 members	25,131.78
		Total cost in USD (1 USD = 7.7584 HKD)	**USD41,588.11**

Table 3: Table of total expenditure for Epoxsea Inc. for the development of the Stingray

System Interconnection Diagrams

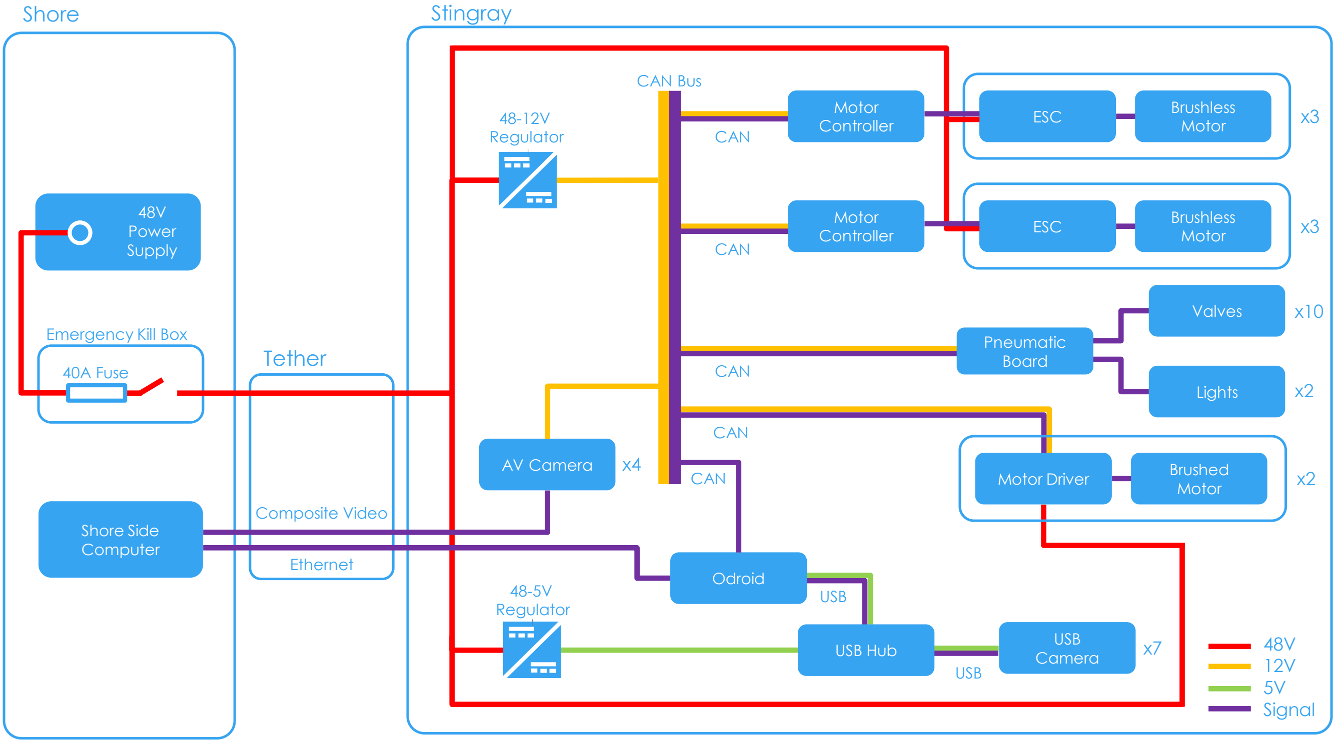


Figure 5: Electronic System Interconnection Diagram

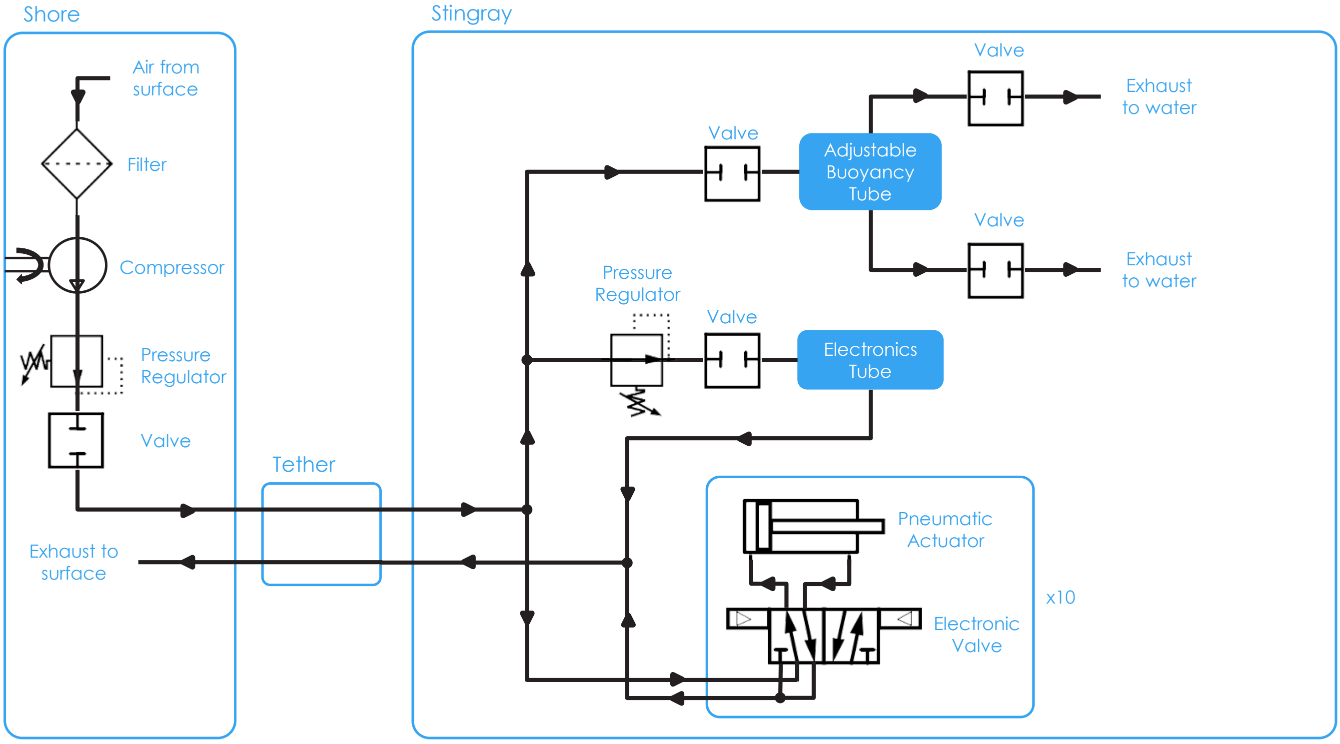


Figure 6: Pneumatic System Interconnection Diagram

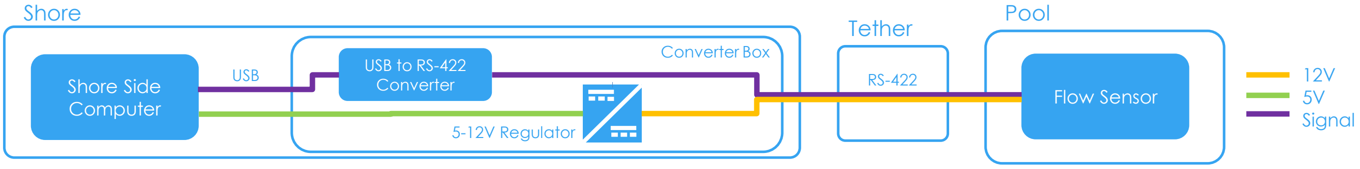


Figure 7: Independent Flow Sensor System Interconnection Diagram

Design Upgrades

Over the years, we have refined the ROV's by leveraging experience from previous years. This is clearly evident when comparing the Stingray with previous machines. The Stingray, (see Figure 8) is clearly the smallest vehicle developed by Epoxsea Inc, yet due to advances in technology, it is the most powerful, flexible, and agile. Using what we have learned in previous years, the Stingray's frame was designed with flexible mounting options to adapt to the different mission profiles; the thrusters were upgraded to brushless thrusters for increased power, and a custom made buoyancy float was designed for better performance. All of these improvements stem from the development from previous years, and there will surely be more in the years to come. The way components are created have also improved. The Algae collector is a prime example of this. It has gone through multiple design ideas, two functioning prototypes, and many iterations of testing and tweaking to ensure that the design is the best possible version to accomplish the given task.

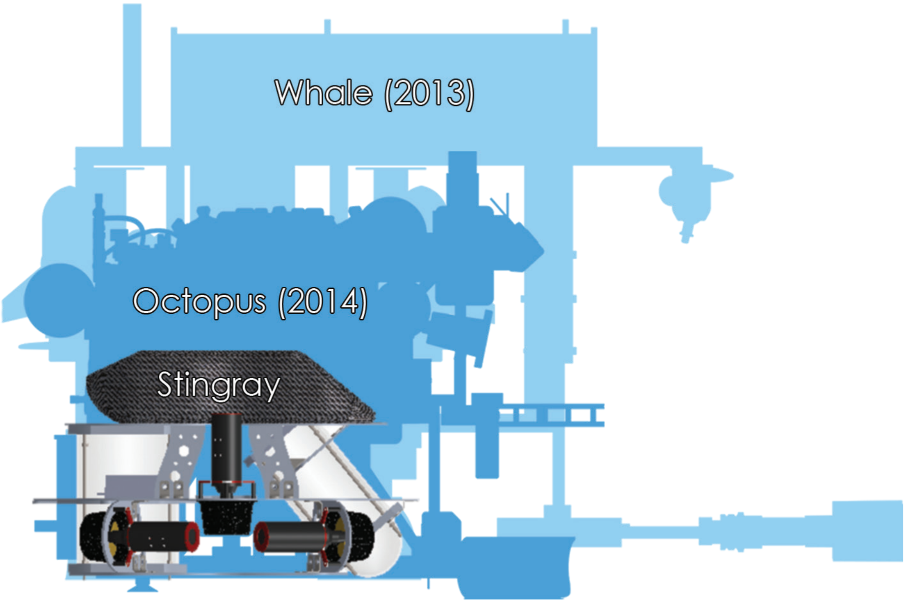


Figure 8: Size comparison of the Stingray and previous ROV's

Safety

Safety Philosophy

Safety is of great importance to Epoxsea Inc. and is always taken very seriously. Numerous safety measures are strictly imposed during the designing, building, handling and testing of the Stingray, with numerous safety features being implemented.

Lab Safety Protocols

During the design and development of the Stingray, a number of safety protocols had to be followed when working in the lab. Appropriate safety equipment, such as safety goggles and ear protection, were used when handling power tools. Masks were always worn when working with fiberglass, to prevent the inhalation of the minuscule fibers. A ventilation fan was also used when soldering or grinding, removing the particulate matter and fumes from the lab, keeping the air in the lab cleaner and safer for the company members.

Safety in Handling the Stingray

For the safety of our members, at least two people must be present when lifting or transporting the Stingray. In addition, all members must have their hands off the Stingray before power is turned on. Most importantly, a safety checklist must be rigorously followed during every water test to ensure both the safety of members and the optimal running of the machine.

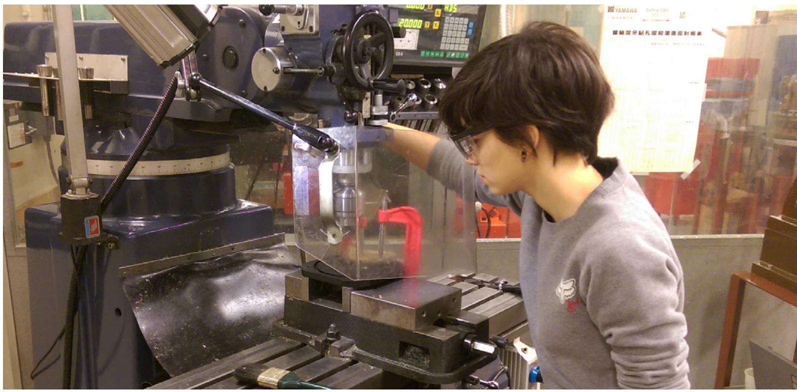


Figure 9: Lab safety protocols used by Epoxsea Inc.

Stingray Safety Features

The mechanical division ensured the absence of sharp edges, installed thruster guards, and added pressure regulators to prevent injuries. Lights were added to increase the visibility of the machine, and warning stickers were also added to highlight dangerous components.

The electronics division installed an emergency kill box after the power supply. The kill box, which includes an inline 40A fuse to prevent short circuits, is designed to cut off power to the Stingray immediately. Cables were also made dummy-proof, to prevent mismatched cables from being connected, which could damage the machine and threaten people.

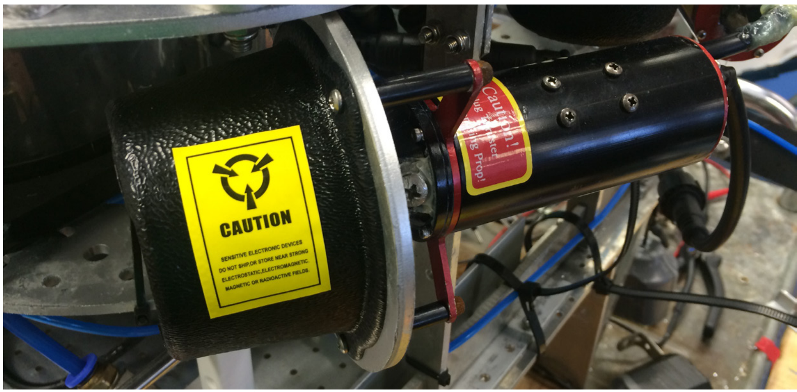


Figure 10: Hazard stickers present on the Stingray

The software division implemented a watchdog timer on the motor controllers. If the connection is lost or if there is any data corruption during transmission, the motors will automatically switch to an idle state (stop turning). In addition, motor ramping is implemented on both the control software and the motor controller, to prevent current spikes that can damage the motor or cause feedback that could potentially destroy the rest of the electronics on the Stingray.

Safety integrated at it's core

Not only are our engineers at Epoxsea Inc. Implementing safety features to the already built Stingray, but they are being thought about from the very beginning of the development phase. The structural integrity is verified before production of any components. This ensures that any new components do not add extensive stress to the framework, which would lead it to a potentially hazardous failure in the long term.

Figure 11: Emergency kill box with inline fuse

Safety Checklist

- ☐ Check for any loose objects or any physical signs of damage on the Stingray.
- ☐ Ensure proper wire connection and presence of silica gel in electronic tube.
- ☐ Ensure that all waterproof connections have O-rings and are sealed tightly.
- ☐ Close and seal the electronic tube.
- ☐ Switch the air compressor on, ensure the pressure complies with the MATE requirements, and check for any air leaks on the Stingray.
- ☐ Check that the voltage on the Stingray side of the tether is 48V, and that the output of 48-12V and 48-5V regulators are 12V and 5V respectively.
- ☐ Start software systems on the shore side computers.
- ☐ Test all systems, including thrusters, pneumatic hands and cameras on deck.

After all systems are checked, the Stingray is ready to be deployed.

Vehicle Core Systems

Mechanical

Framework

In order to reduce the size of the Stingray, while still being able perform all three sets of mission tasks, the frame, developed by Rayan Armani and Johannes Jaeger, includes copious mounting options, which can be used on a per-mission basis as needed. The frame was made with three layers to provide as many mounting options as possible while reducing the cross-sectional area, to reduce the amount of drag. By standardizing the screws used on the Stingray to M3, M5 and M8 sizes, we are able to reduce the inventory of screws, which allows easier development and maintenance. The frame is made using 7075 grade aluminum alloy, which was selected for its lightness, strength and durability. The aluminum is anodized to prevent corrosion, which is crucial, as corrosion is accelerated by the presence of the water.

Electronic Tube

The Stingray features an acrylic tube that is used to house the main electronics. This tube is mounted at an angle, which permits the installation of an acrylic dome on the end, allowing the installation of a pan-tilt camera, which gives the pilots more flexible viewing angles. The position of the electronic tube is inclined for two reasons - to reduce the drag forces and to maximize the field of view of the camera. In order to reduce the amount of condensation, we added silica gel and maintain a continuous flow of air through the tube.

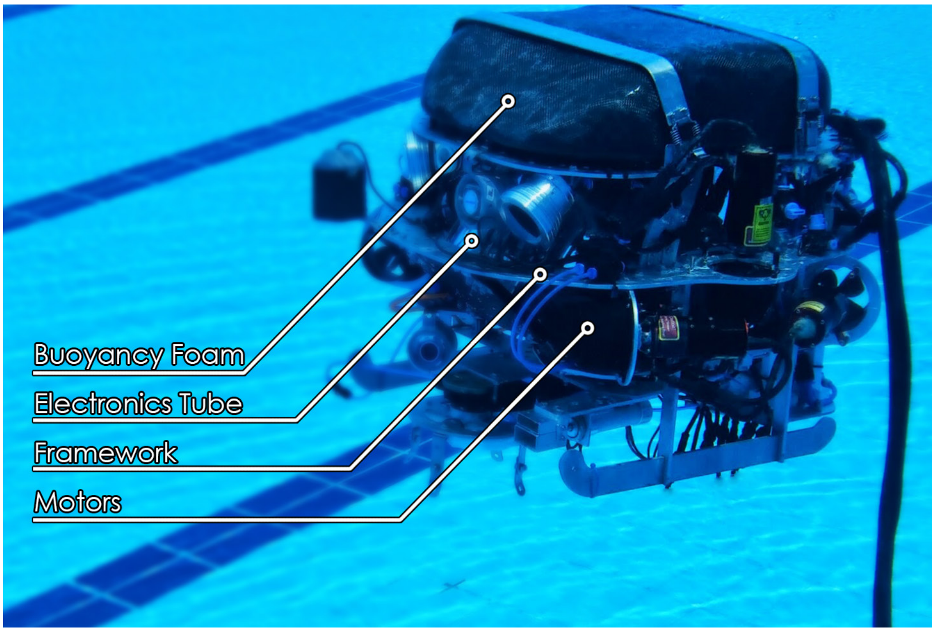


Figure 12: Labeled image of core Stingray systems

Buoyancy System

Custom made foam floats were engineered to keep the Stingray neutrally buoyant. These floats were initially modeled in CAD, in order to identify the most aerodynamic shape for reduced drag forces and therefore, improved performance. After shaping the foam we covered the foam with layers of fiberglass and carbon fiber, to prevent deformation as the Stingray descends underwater. In addition, the Stingray features an adjustable buoyancy tube (ABT), which can be filled with water as needed to tune the buoyancy to as close to neutral as possible for maximum performance. The use of the ABT also allows the buoyancy to be adjusted to compensate for the weights of the different manipulators that are required for the different missions.

Motors

Six brushless motors power the Stingray and provide superlative thrust. Each motor is capable of producing 130W of power, which translates to 4.5kg of thrust. The four horizontal motors are positioned at an angle of 30 degrees relative to the forward and backward direction of the Stingray, which allows for greater forward speed, while still allowing for drifting capabilities to the left and right. The remaining two motors are fixed in the vertical axis and are responsible for movements in the vertical direction.

Electronics

Seaking–HV80A ESC Motor Drivers

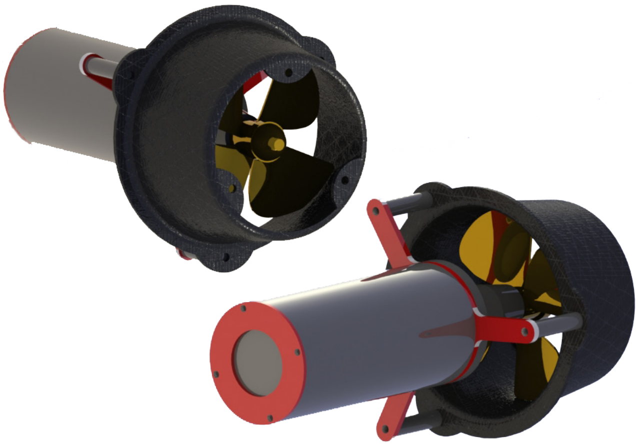


Figure 13: The Crustcrawler 400 HFS-L motors

The Stingray is equipped with Crustcrawler 400 HFS-L brushless motors, which are favored for their higher power to weight ratio when compared to the brushed motors used on previous Epoxsea Inc. ROV’s. However, driving brushless motors requires a complex electronics sequence. After comparing our in-house motor drivers against the commercial Seaking-HV80A ESC, the commercial drivers were chosen because they outperformed ours by a great margin.

CAN Architecture

Poor cable management has been an issue with previous ROV’s. This can be attributed to the use of a single central microcontroller, which requires one cable per external device, i.e. pneumatic valves or motor drivers, which creates issues when many components are added. To solve this problem, the Stingray uses multiple microcontrollers connected over a network instead of one large central microcontroller. The architecture was developed by Dhesant Nakka, using the Controller Area Network (CAN). The CAN architecture has many advantages that are favorable for the Stingray; it has a shared bus, so only two cables are required to control a virtually unlimited number of nodes. These nodes can core systems, such as motor controllers, pneumatic valves, or the main processing units, or they can be specialized for certain applications, such as mission specific manipulators or sensors. Because CAN uses differential signaling, it is highly noise resistant, which is necessary with the electromagnetic noise generated by the motors, and has more than twice the bandwidth of other communication protocols such as SPI, I2C or UART.

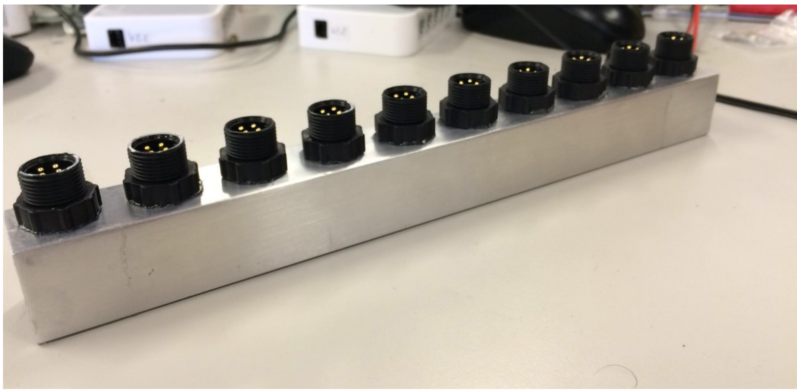


Figure 14: The main CAN bus hub

ATmega32M1 Microcontroller

In 2014, we used the STM32F407VG as our main microcontroller, which was attached to a large extension board to interface it with all the external devices. With the addition of the CAN bus, we did not need to have a microcontroller as powerful, so instead, the Stingray makes use of multiple smaller ATmega32M1 microcontrollers, which are used on the motor controllers, pneumatic boards and other sensors. Since they are modular in nature, it makes the system easily scalable.

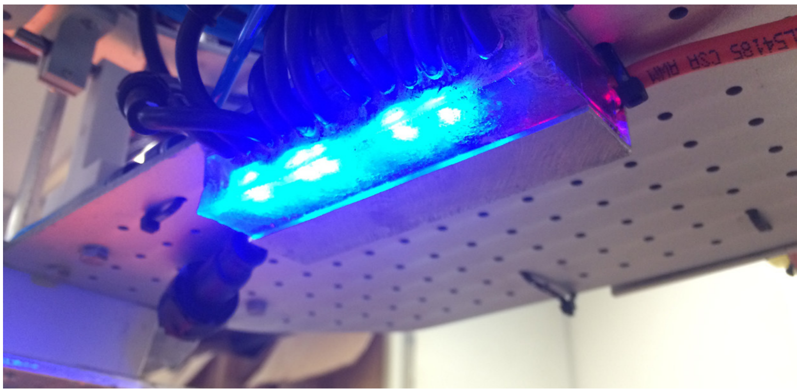


Figure 15: An ATmega32M1-based pneumatic board

Software

As shown in the software block diagram (Figure 16), the shore side operations are done on a single computer, which is responsible for controlling the Stingray, viewing the cameras, calculating different measurements, and keeping track of mission progress. The Stingray itself is controlled by an Odroid-XU3, which is connected to the shore via TCP/IP over Ethernet. Messages are sent to the Odroid by the Robot Operating System (ROS), which are then translated to CAN messages and are then sent out via the CAN Bus to Atmel ATMega32M1 microcontrollers. Microcontrollers were programmed to perform their functions independently from one another in order to achieve modularity.

The goal of this year's software system was similar to the rest of the company, to achieve a high level of modularity. Flexibility of the Stingray's communication system, and the ability to hot swap entire subsystems were also high priority targets for this year's software development.

ROS

A new framework used for the Stingray's software architecture is the Robot Operating System (ROS), which was implemented by Long Hoang. ROS was chosen because it allows for parallel peer-to-peer communication between the different nodes, no matter whether they are on the Shore, or the Stingray. Although the central instance, called the ROS master, manages the interconnections between the different nodes, data transfer is done ad hoc between the respective nodes.

This notion of decentralization gives the Stingray's communication network a lot of flexibility. For example, nodes that are in charge of handling mission-specific manipulators or sensors can be hooked into the Stingray's control system on the fly, and thus, enabling

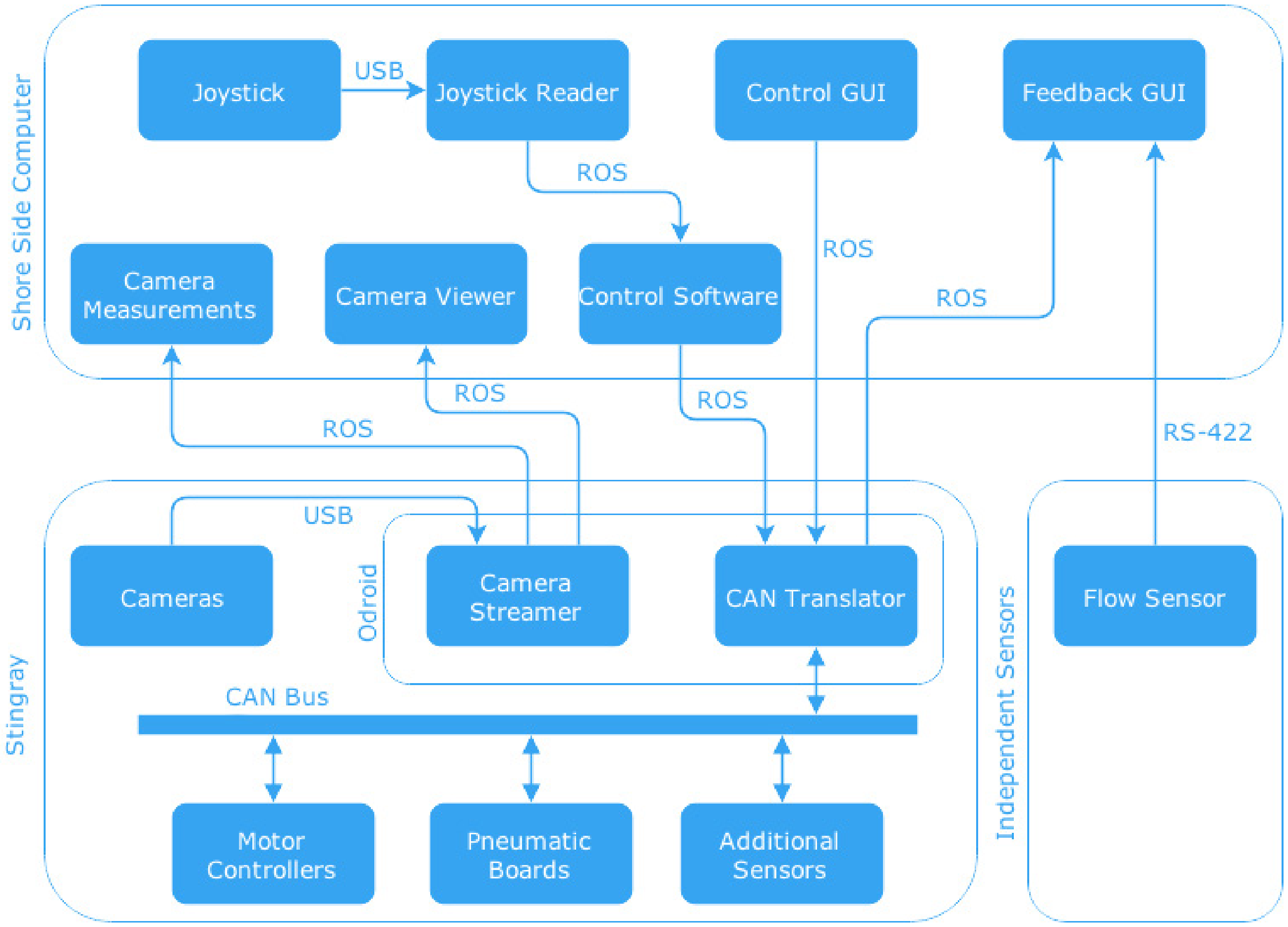


Figure 16: Software block diagram

hot swapping of different subsystems in between missions without spending time reconfiguring the system.

Another advantage of ROS is that the different nodes can be developed and tested individually, so the GUI, developed by Mikaela Uy, can be completely rebuilt without worrying about how it would affect other nodes, such as the CAN translator developed by Albert Tanoto. This is aided by ROS's virtualization features, which allow the system to emulate real life nodes, so the software can be tested in a fixed environment, easing development.

Odroid-XU3
The Stingray's main computing unit, the Odroid-XU3, was chosen because of its favorable computational power in a smaller form factor. The Odroid contains one dedicated USB 3.0 host, giving the Stingray a much higher bandwidth for cameras compared to last year's Raspberry Pi, which is necessary, because without suitable bandwidth for cameras, the latency of the video feed increases, which makes it harder to pilot the ROV. This year we were able to drive 5 cameras at 30fps with a resolution of 320x240 compared to 3 cameras at 10fps 160x120 a year ago. The Odroid also serves as the ROS master and is where the translation between ROS to CAN messages takes place. The Odroid's operating system was also tweaked to boot up in 14 seconds , less than half the previous time, and shut down in 100 milliseconds, compared to 15 seconds, to achieve faster mission ready times.

Motor Controller
Each motor controller, developed by Long Hoang and Andreas Widy, drives 3 motors simultaneously using one of the Atmel ATmega32M1. Additionally, a watchdog timer is implemented that continuously checks whether a predefined 'keep alive' signal is received, shown in the flow chart in Figure 17. In case of any malfunction, this signal will fail to appear, which triggers the controller to set all motors to pre-operational mode (idle but ready to go).

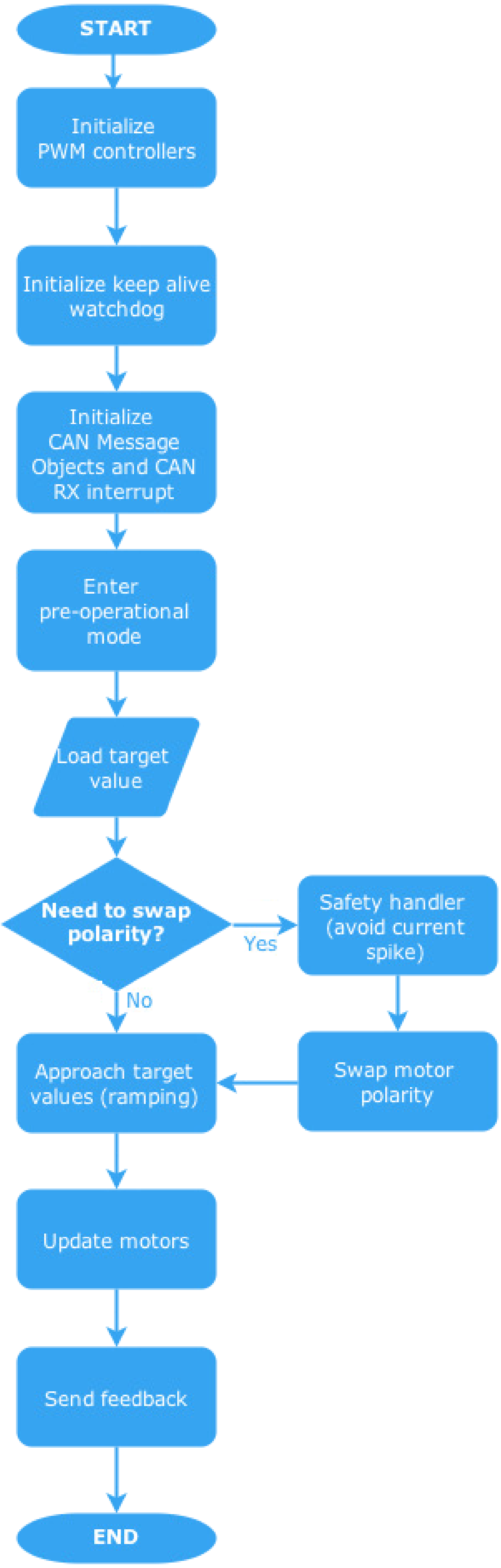


Figure 17: Motor controller software flow chart

Mission 1: Science Under the Ice

Since this mission is very software intensive, we realized that we would heavily rely on cameras in order to take timely and accurate measurements. This comes with the added challenge of low visibility due to the layer of ice covering the water. Being aware of this challenge and trying to reduce some of the complexity for the control crew as well as reducing the burden on the software division, the hardware and mechanical engineers worked closely together to improve the situation as far as possible.

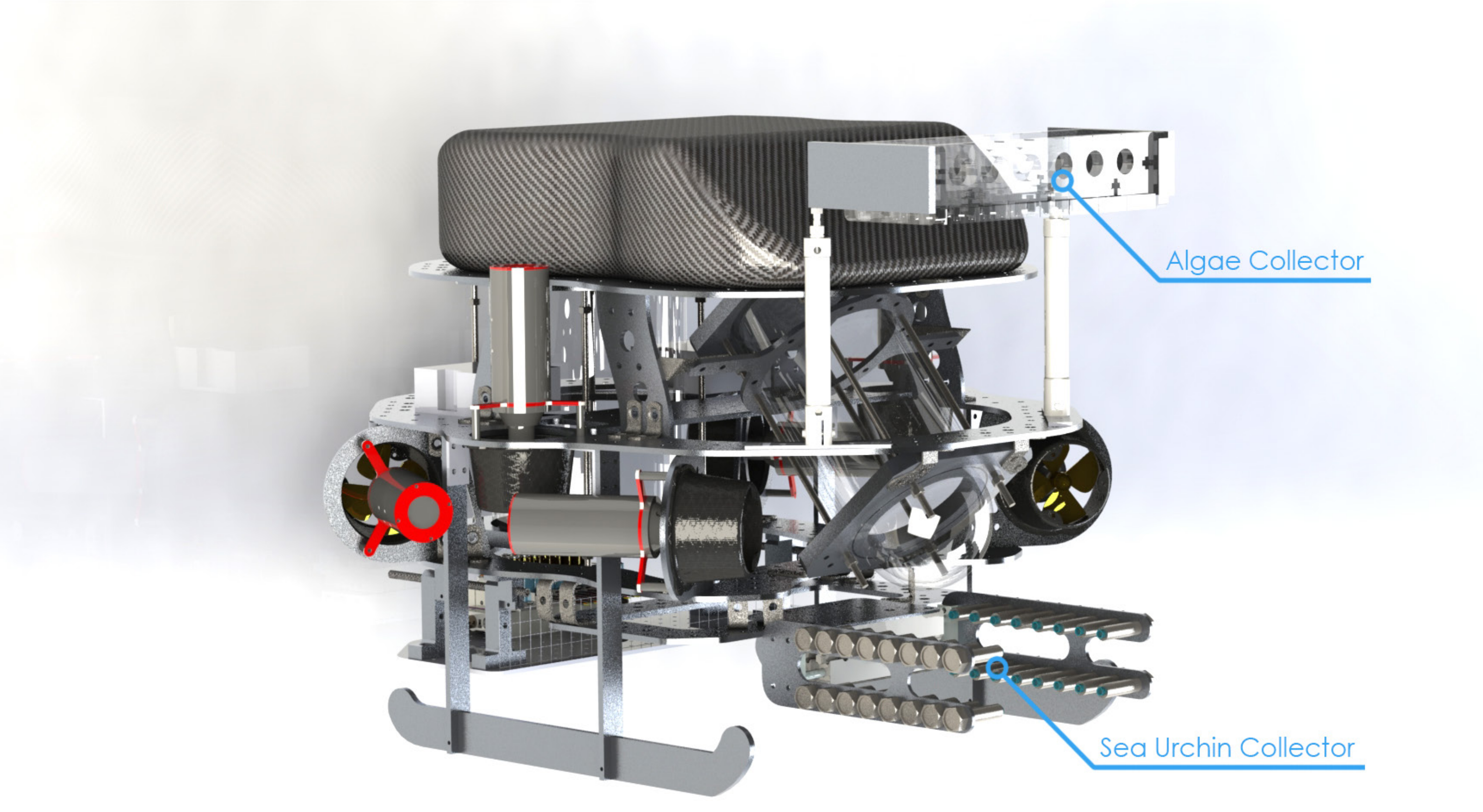


Figure 18: CAD model of the Stingray showing Mission 1 manipulators

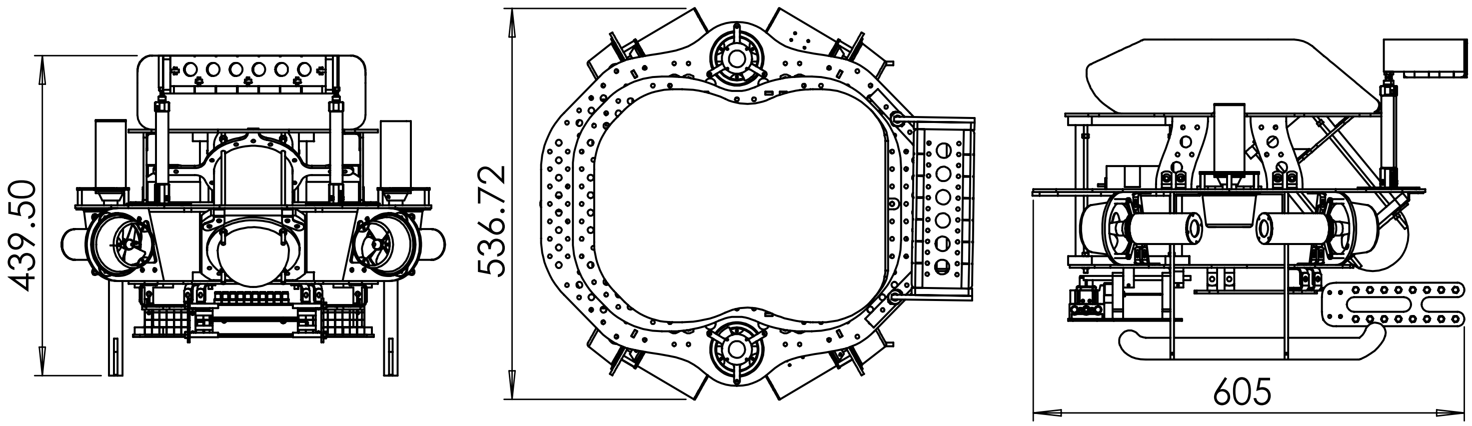


Figure 19: CAD drawing of the Stingray with Mission 1 manipulators (dimensions in mm)

Figure 20: CAD model of the algae collector

Algae Collector

Elvin Ruslim and Christian Edwin Pranata designed a manipulator to retrieve an algae sample from under the ice sheet.

Initially, the design was to have a motor that sucked the algae sample in. However during testing, it was found that the chosen motors, bilge pumps, did not have enough power perform the task. Instead, the design was changed to an open box structure, shown in Figure 20, with elastic bands across the face of the opening. The long and narrow design was chosen to aid the pilot in capturing the sample while avoiding the uneven surface of the ice. The sample would be forced into the box by projecting the box upwards, and the elastic bands would retain the sample in the box. This mission is especially difficult because abrupt movements will easily dislodge the algae sample, hence the collector is equipped with pneumatic actuators to reduce the amount of movement needed to be carried out by the Stingray.

Mission Helper

To aid the Stingray pilots, a web-based application was developed by Dhesant Nakka to assist the pilots in keeping track of any information required for the different missions. These include showing the remaining time for the mission and the mission tasks in sequence. In addition, different calculators were added, such as a threat assessment calculator to aid the pilots to see whether the iceberg presents any danger to the different oil platforms and a calculator to keep track of the each type of sea star. This tool also reduces the risk of forgetting to complete any tasks, which has been a problem in previous years.

Task	Points	Status	Time
Retrieve Algae Sample	10	☑	0:54
Retrieve Sea Urchin	10	☐	
Identify Sea Stars	10	☐	
Deploy Passive Acoustic Sensor	10	☐	
Survey Iceberg	5	☐	
Measure Iceberg	25	☐	
Map Iceberg	10	☐	

Iceberg Depth: 85 m
Iceberg Location: 46.78 -48.78
Iceberg Heading: 90 °

Surface: Hibernia
Subsea: Hibernia

Figure 21: The mission helper software

Iceberg Measurements

One of the mission requirements is to determine the diameter (x1 + x2 in Figure 22) and keel depth (y in Figure 22) of the iceberg. To decrease the required time, Joel Berago developed a system which only requires one image to calculate both measurements. Because the image can be taken at any time during the mission, the pilot to focus on other tasks while the software specialist looks for a good image to use.

Since we know that the length of sections labeled a and b in Figure 22 are 30cm long, we are able to utilize a simple linear function, that compares pixel length of a and b against x1, x2, and y, and with the reference length of 30cm, we are able to calculate the diameter and keel depth from these ratios.

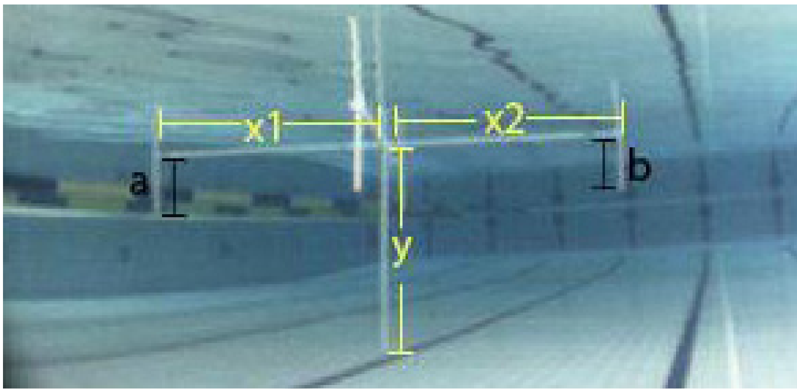


Figure 22: Reference image of the iceberg

Mission 2: Subsea Pipeline Inspection & Repair

Surface waves, fixed mission sequence and delicate operations were all challenges faced in the development of the approach for this mission. This mission was seen to be very mechanically intensive, and hence our mechanical division spent a lot of time perfecting and tuning the manipulators for this mission.

Another key constraint was space. Due to the smaller size of the Stingray, there was less space available for mounting all the manipulators. This required the mechanical division to make sure the design was as compact as possible, without compromising on quality.

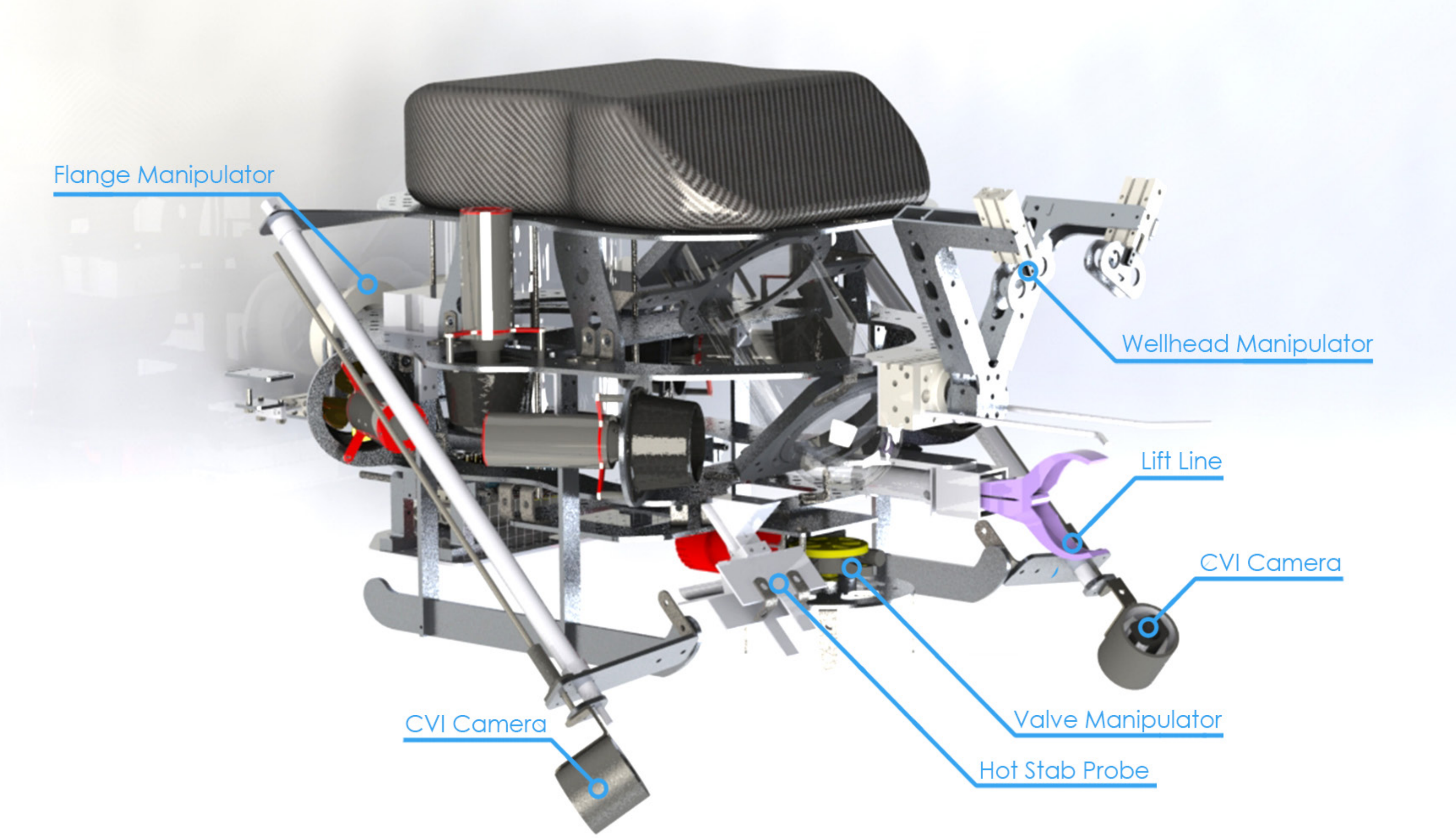


Figure 23: CAD model of the Stingray showing Mission 2 manipulators

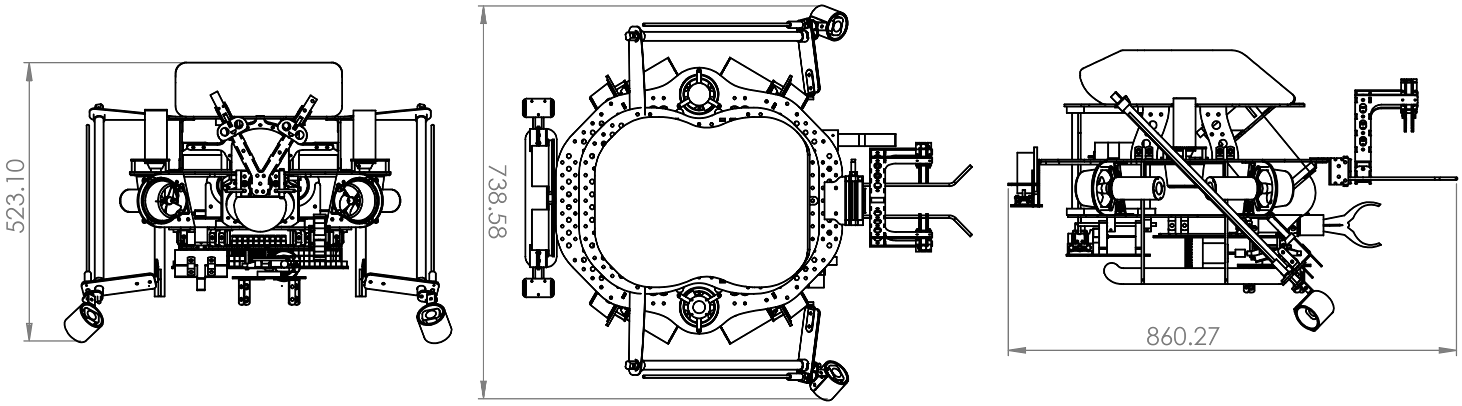


Figure 24: CAD drawing of the Stingray with Mission 2 manipulators (dimensions in mm)

Lift Line

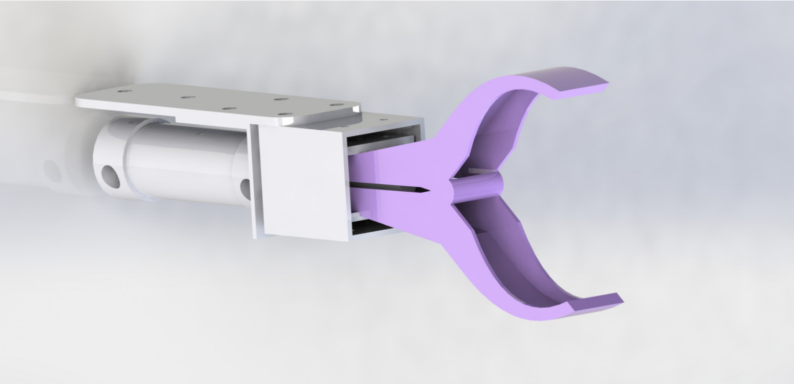


Figure 25: CAD model of the lift line

In order to retrieve the corroded pipeline, a lift line, designed by Rayan Armani, was built. A spring loaded clamp is kept in the open position using a shroud on the Stingray. When the clamp is positioned over the corroded pipeline, a pneumatic actuator will drive the clamp out of the shroud and lock it onto the pipe segment, at which point the shore crew can retrieve the corroded pipeline. This approach was chosen because the spring loaded clamp can be easily purchased, which saves development time and resources for more intensive manipulators.

Wellhead Manipulator

In order to successfully prepare the wellhead for the delivery of a Christmas tree, a specialized manipulator was designed by Haichen Gu to accomplish the entire sequence of tasks using one manipulator. As shown in Figure 26, this V-shaped manipulator is completely made of puzzle structured glass fiberboards. A rotary cylinder switches between the two actuators, and a guide is installed to help position the Stingray accurately. One of the actuators is designed to pick up and replace the wellhead cover, while the other is designed to drop the gasket into the wellhead. This approach was chosen because getting the Stingray to rotate by exactly 20 degrees is very hard given the large inertia that is has and the additional forces presented by the waves, instead, the pneumatic actuators can reach this level of precision very easily. In addition, the guides were discovered to be very useful for cutting the section of pipeline, making the manipulator very versatile.

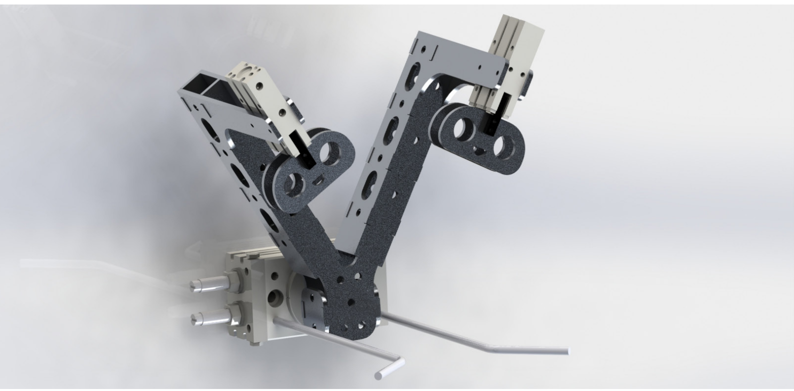


Figure 26: CAD model of the wellhead manipulator

Flange Manipulator

In order to decrease the amount of time spent on this task, our mechanical engineer, Haichen Gu, designed a manipulator which holds both of the flanges and their required bolts. When the Stingray is deployed, the bolts would already be inserted into the flanges, and once the pilot successfully places the flange, a pneumatic actuator would lock it in place instantly. In order to increase the accuracy of the pilot, a camera was installed behind each flange. This design allows all the task requirements to be completed in one operation, which reduces the amount of time the Stingray spends maneuvering, decreases the load on the pilot and allows the pilot to focus on other tasks that are required for this mission.

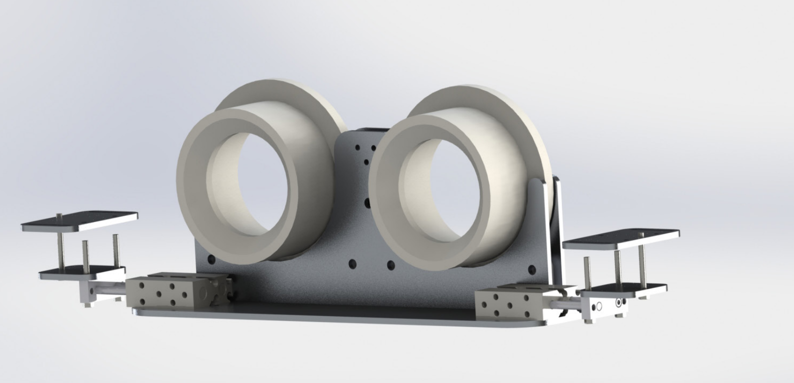


Figure 27: CAD model of the flange manipulator

Mission 3: Offshore Oilfield Production & Maintenance

This mission features many repetitions of similar tasks, namely the testing of different anodes and manipulating several valves. In order to reduce the number of times the Stingray would need to do the mission, the mechanical division designed a probe that can test 4 anodes at once. In addition, we tried many different camera positions to view the valve manipulator, in order to give the pilot the best point of view, since targeting should be very straightforward as it needs to be done multiple times.

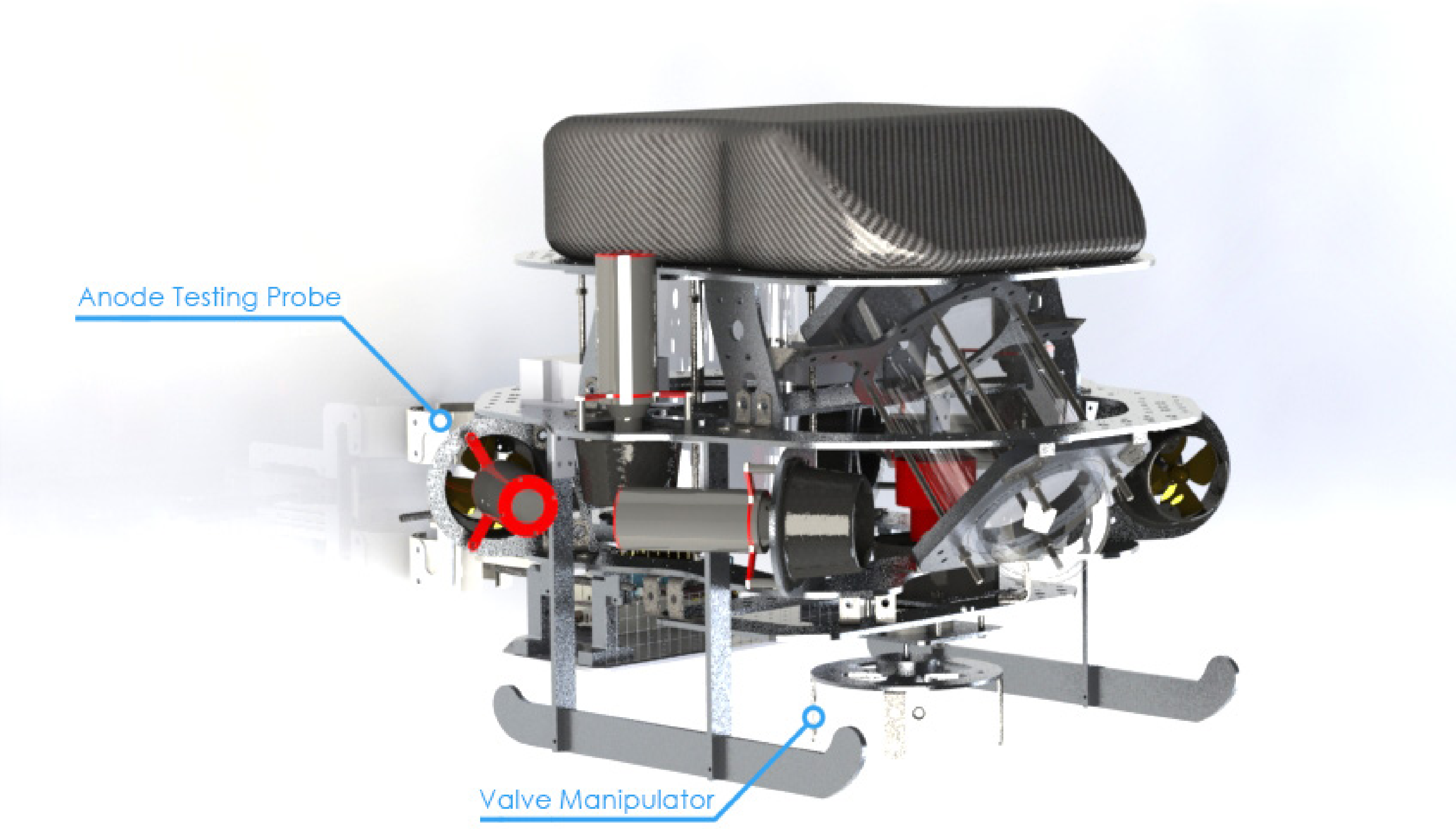


Figure 28: CAD model of the Stingray showing Mission 3 manipulators

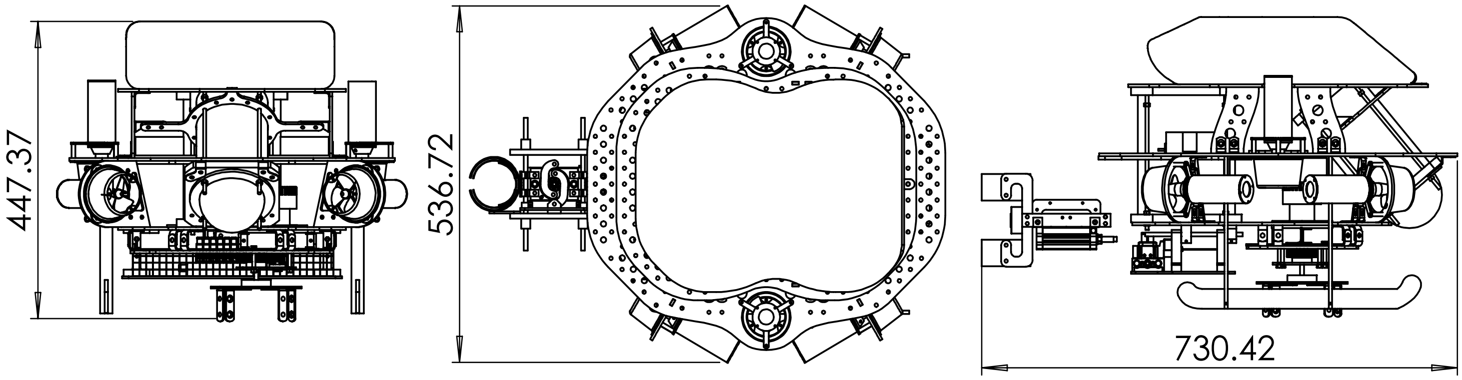


Figure 29: CAD drawing of the Stingray with Mission 3 manipulators (dimensions in mm)

Anode Testing Probe

Haichen Gu and Andreas Widy designed this probe using metal sponge and PVC. The probe was designed to grab all the test points at once to reduce the time spent on the mission, and it is spring loaded, so it can grab onto the pipeline no matter which angle it is at.

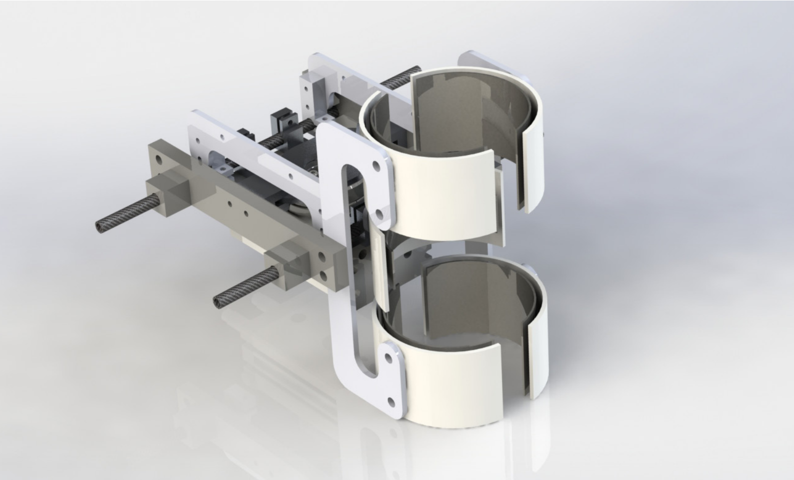


Figure 30: CAD model of the anode testing probe

The probe makes use of the on board Analog to Digital Converter (ADC) on the ATmega32M1 to test the grounding of each anode. Five test points were chosen, four on the pipeline, and an additional one in the water. The fifth test point was chosen because it allows the microcontroller to determine the voltage bias induced by the water, which can be accounted for when calculating which test points were properly grounded, allowing for a flexible and robust data collection solution. The collected data can then be sent to the shore computer for analysis.

Water Flow Sensor

In order to increase the accuracy of our water flow sensor, Elvin Ruslim, Yiyang Tang, and Mikaela Uy developed a self orienting sensor. The fin attached to the top of the sensor orientates the sensor into the direction of the flow. Half of the flow sensor is covered with a plastic shroud to ensure the impeller is only spun in one direction. The design of this sensor is very economical, since it was created using recycled materials that were present in the lab.

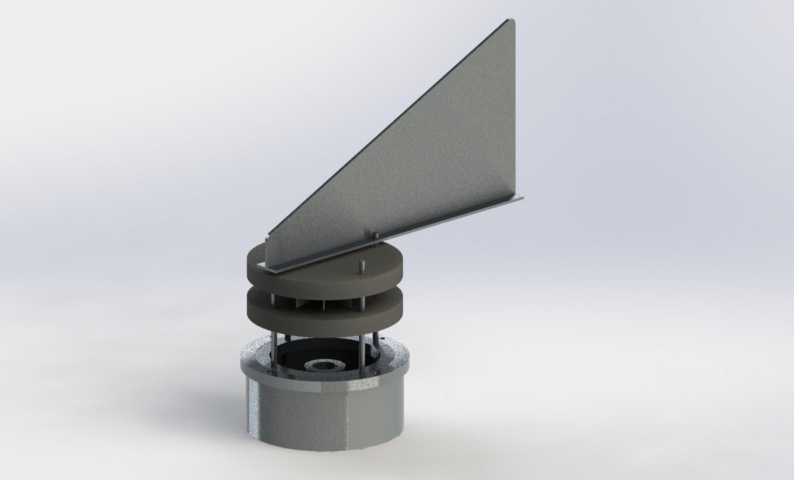
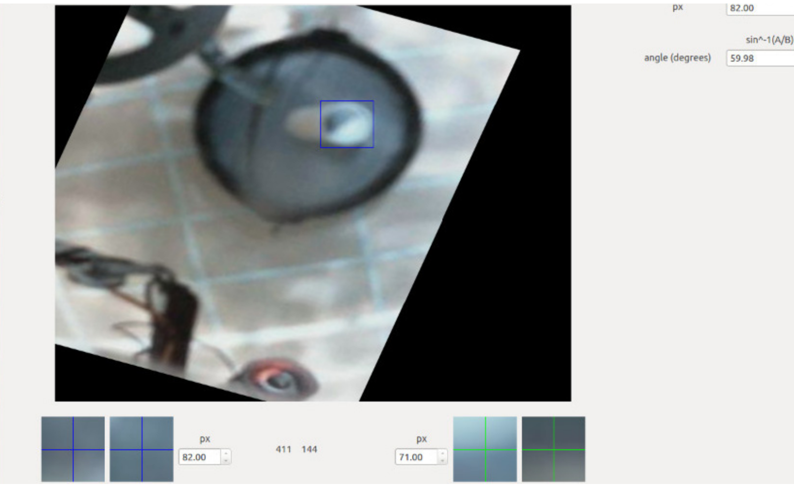


Figure 31: CAD model of the water flow sensor

Wellhead Measurements

Similar to the iceberg measurements, the wellhead measurements are done with a monocular camera system. The aim was to be able to calculate and derive all three measurements (length, height, and angle) in as few images as possible to save time for other mission tasks. This is done by taking the projected view of top of the wellhead, which forms an ellipse. The angle can then be calculated using the ratio between the major and minor lengths of the ellipse. Another image can then be used to calculate the length of the wellhead using a similar method as the iceberg calculations in mission 1, then the height can be derived with simple trigonometric formulas from the other measurements.



px 82.00
sin^-1(A/B)
angle (degrees) 59.98
px 82.00
411 144
px 71.00

Figure 32: The wellhead measurement software

Troubleshooting Techniques

Buoyancy Foam

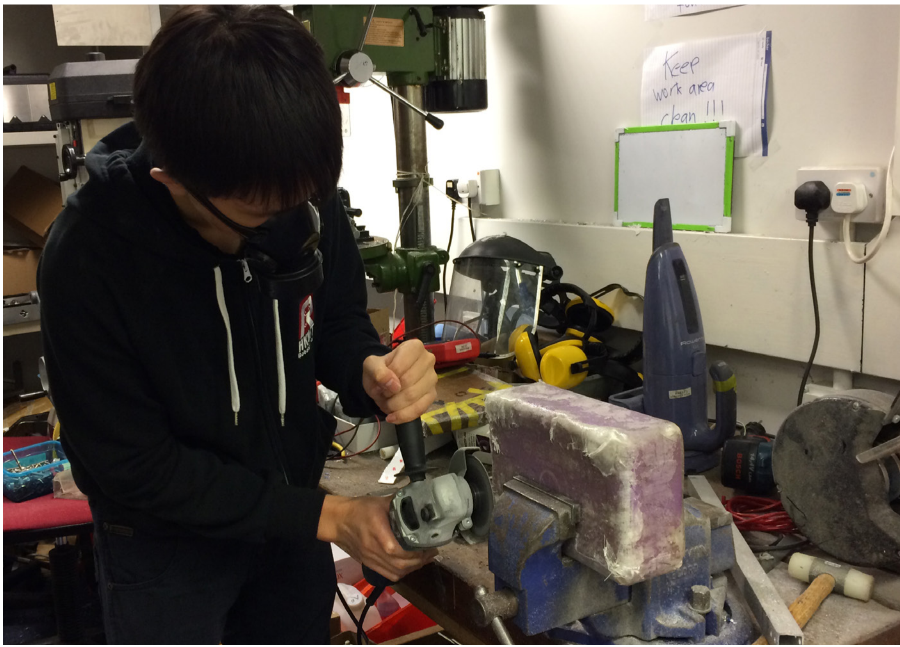


Figure 33: Process of building the buoyancy test blocks

Epoxsea Inc. had several years of experience of using different types of materials for buoyancy, from PVC tubes to adjustable buoyancy tubes and to pool noodle foam. This year, Elvin Ruslin and Dhesant Nakka experimented with the use of custom shaped Styrofoam floats, strengthened with fiberglass and carbon fiber. Four years ago, we used pool noodle foam for buoyancy. The foam worked fine in shallow water environment (1-2 meters depth). However, as the ROV descended, the foam became compressed due to the increased pressure, which reduced the buoyancy it provided and causing the ROV to descend deeper until it became stuck on the bottom. Secondly, the use of custom shaped Styrofoam stems from our experience with using PVC tubes for buoyancy in the last few years. The PVC pipes only come in few standardized sizes and only in cylindrical forms, which are not as space efficient as it can be, while also providing very few possible mounting options, which makes the ROV very bulky.

The buoyancy foam is covered with four layers of fiberglass and one layer of carbon fiber, which we calculated to the optimal number of layers for the foam to withstand the pressure. To create a suitable shape, we first needed to estimate the weight of the Stingray. This was done by using the PVC tubes to make the Stingray neutrally buoyant, then calculating the volume of the cylinders that were required to achieve this. In addition, we also needed to calculate the buoyancy force provided by foam with different layers of fiberglass, which was done by covering some test blocks with different layers and measuring how much buoyancy they can provide. Finally, we needed to calculate how many layers of fiberglass are needed to withstand the required pressure, which was done by placing the different test blocks in a pressure chamber and seeing how they deformed at different pressures.

Thruster Issues

Brushless DC thrusters are vastly different to the brushed DC based thrusters used on previous ROV’s. They are more complicated to drive, since electronic control is required.

We used commercial RC ESC’s to control our thrusters, however they do not have any feedback mechanisms and implement their own proprietary control algorithms, which meant that exhaustive testing was needed to correlate the input signal to the desired power limit, to prevent the motors from going over specification. This is especially important because the motors, 400W brushless motors, had to be limited to 130W because the generated heat would build up because of the waterproofing. We also had to develop our own ramping algorithms for two reasons, the first is to protect the gear box, as sudden changes in power could damage it, and the second would be to prevent the ESC’s from entering over-current protection mode, which would deactivate the motors.

Stingray Testing

Building the machine is just half the story. One of the key factors which differentiates our machine from most other companies' is the fact that the Stingray has undergone over 70 hours of mission testing. We usually have three-hour water tests twice a week, during which we train our control and shore crew. The first few water tests were used to allow everyone to try different roles, and then the best possible candidates were determined at the end of the second week. After each water test, we would hold a meeting, where we evaluated what happened during the test in order to see whether there was anything that was needed to be done before the next. It was crucial for the control and shore side to share their observations and raise issues during the meeting so that a plan of action can be made in order to improve the performance of the Stingray and persons in charge for the tasks can also be assigned.

From idea to machine

The Stingray would not have been as good as it is without the underlying framework and methodologies that we acquired over the years, which were applied during the development of the Stingray. To better understand this process, let us take a closer look at how the algae retriever was made. During initial meetings, the mechanical division came together and started brainstorming different design ideas to achieve the task, and the strengths and weaknesses of each design would be deliberated after. After a number of iterations of this process, a plausible design is created that combines the features of many initial ideas. For this specific example, two different designs were determined to be feasible, so both of them continued through the design process. The next step of the process is to create a 3D CAD drawing of the part, which allows us to get a better sense of how the design is built and also allows us to see any potential pitfalls before its actual manufacturing. In the case of the algae retriever, both designs seemed feasible to manufacture, hence prototypes of the two designs were created and tested on the Stingray in order to evaluate their performances. We then found out that one of the designs, which was using a pump to suck the sample, was not strong enough, so this design was dropped, and the second box trap design was further developed and refined in the next water tests. The development process is always ongoing, as during latest tests of the new design, the pilots identified that the pneumatic actuators were not long enough to grab the sample successfully, which was rectified soon afterwards. It is important that all members are equally involved in the design process to ensure that the best ideas get put forward, and just because a manipulator gets manufactured, it does not mean that the design is finalized because in the end it is all about building the best we possibly can, even if that means completely redesigning a part.

Lessons Learnt

Cameras

A key issue from previous ROV's is latency in the video stream, which can be as bad as a few seconds, which made it very difficult for the driver to have good and accurate control of the ROV. In order to avoid similar issues this year, we decided to use AV cameras, implemented by Yiyang Tang, which have minimal latency. However, this is not without it's own issues. The AV camera housing is very small, which does not provide space to add silica gel that is required to prevent condensation. Initially, the AV cameras were just coated with epoxy resin to waterproof them, but that proved to be unusable, since the trapped moisture condensed onto the lens. After a lot of experimenting, we discovered that setting the epoxy on a vibrating surface would help the moisture escape.

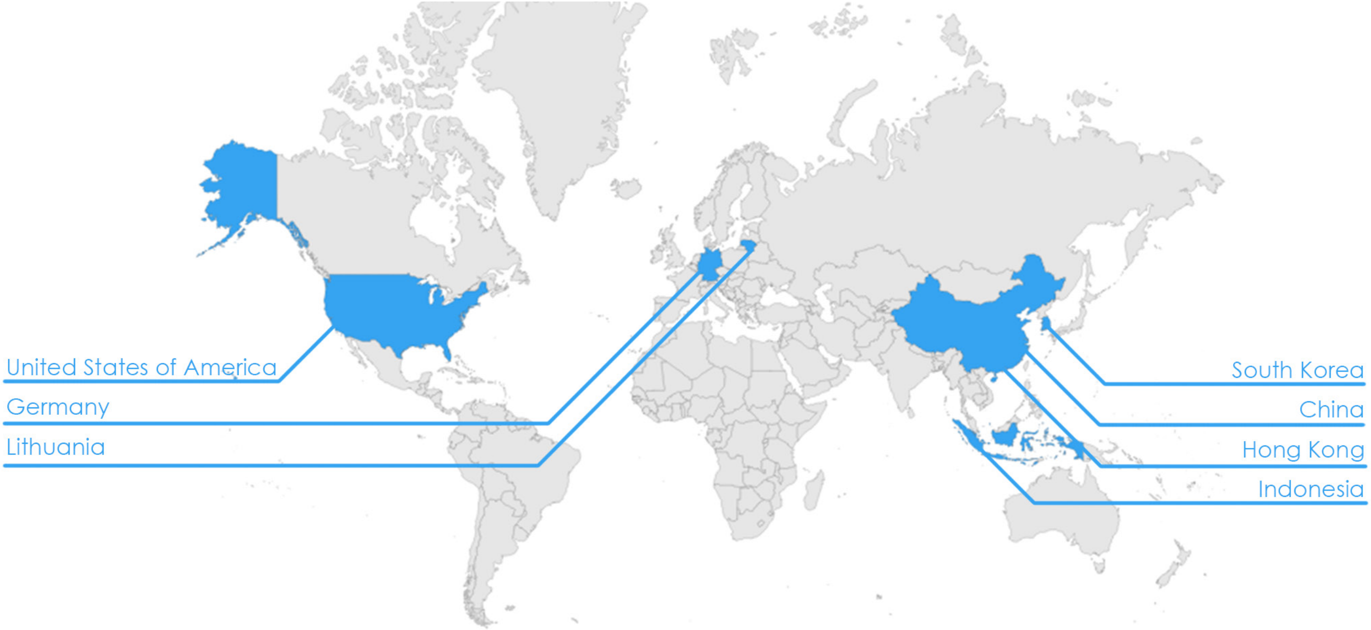


Figure 34: Map of locations that components are sourced from for use on the Stingray

Location

Location, location, location. These days, location can be a key success factor, and Epoxsea Inc., being headquartered in Hong Kong, has been able to take advantage of this. In previous years, we have only been leveraging our connection with Mainland China. However this year, we have started to look into other areas, such as South Korea, Indonesia, Lithuania, USA and Germany. We figured that this is a risk worth taking, since we realized that when having access to more markets gives us a bigger range of products. Mainland China does give us access to many very well priced products, with fast logistics times, however for several products, such as thrusters and microcontrollers, we had to look elsewhere to ensure the best performance of the Stingray.

Research

The major changes in previous Epoxsea Inc. ROV's have been very incremental in nature. However, for the Stingray, we wanted to implement many new systems, which necessitated a lot of research and development time. During the R&D time, we learned that time management and documentation are two key aspects for successful research, which we believe to be critical for the long-term success. Many of the new Stingray systems were developed during this time, and even though not everything that we researched were implemented, going through the process has made all company members better researchers and has help us gain more knowledge in our areas of interest. To ensure that the knowledge can be shared with other members and future teams we would document any findings through articles, photos and videos and upload them to our knowledge database.

Interpersonal

To ensure we had good team collaboration, 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 together after the formation of the team allowed us to get to know each other, and overcome any language barriers that we've had. This was the first time that more than 50% of team members were participating for the second year in a row. Since many of us knew each other very well we started to create our own terminology, for example, the multimeter turned into a 'DMM' and then a ‘beep beep’. For the new members, this was very confusing, as the terminology was very new to them, and they could not search for the answers. However, over time, the newer members became accustom to the terminology. A driving force for improved team collaboration is that, at some point, everyone was in charge of implementing a system onto the Stingray, requiring collaboration with people from different disciplines and backgrounds, resulting in the team working closer together.

Challenges

Technical

Epoxsea Inc. first started using pneumatic actuators two years ago, on the Whale. The valves which we use to control these are very delicate devices which are part mechanical, and part electronic. To ensure they don’t fail, they were placed in a sealed enclosure, but this adds a lot of bulk to the ROV, as evident by the size of the Whale. To reduce the size of the ROV, we experimented with removing the bulky enclosure by waterproofing the valves. Initial efforts were made last year on the Octopus, where the valves were waterproofed by covering them in a layer of epoxy resin. However, this was very unsuccessful, as the valves broke after a few weeks of use.

To develop a better technique for the Stingray, we first learnt how the valves work, and how they failed previously. In doing so, we learnt that we needed to waterproof the internal electronics in addition to the external case, which provides an additional level of waterproofing. This method was much more effective than before, with the valves lasting a few months instead of a few weeks. However, this is still a lot of room of improvement, as maintaining all the valves requires lots of time and effort, and the possibility of failure during a critical time can be reduced with better techniques.

Interpersonal

Since our water tests happened late at night for three hours, one of the biggest challenges was to have sufficient people attending the water tests, especially during deadline-heavy or examination periods. In order to combat this issue, we would always survey the best possible time to conduct the tests and ensure that we would always have at least one mechanical, software and electronics engineer available.

Figure 35: Team building on the beach with a bonfire

Figure 36: (left to right) Albert Tanoto, Rayan Armani, Mikaela Uy

Reflections

“Working with the HKUST ROV Team has definitely given me a fruitful experience. I have the opportunity to learn a lot of new skills and work with people from all around the world. This certainly helps in improving both my technical and soft skills. As one of the software developers of the team, I have been challenged to learn and implement programming knowledge into the practical use of our robot.”
– Albert Tanoto, Chief Technical Officer

“Participating in the competition last year left me with many new ideas and unfulfilled goals that made me want to participate once again. As a senior member in the team, I was not satisfied with just having a working ROV and achieving average results at the competition. I set myself new goals for the upcoming competition, hoping the goal would grow on a team level: designing a robot that would not only perform well but also look special. Whether that was a success or not is yet to be determined, but working on a new ROV with the team was certainly as instructive and fun as last year.”
– Rayan Armani, Mechanical Engineer

“Joining the HKUST ROV Team has added a different flavor to my university life. From designing algorithms and debugging codes to listening to strange music and lame jokes, I truly enjoyed all the sleepless nights filled with both stress and laughter. Working together with this incredible team, alongside these brilliant people from across different countries and cultures, not only was I able to learn a lot of technical skills, but also skills for personal growth. It has been, without doubt, an amazing experience worth cherishing.”
– Mikaela Uy, Software Developer

Future Improvements

Electronic Speed Controller Improvements

The Stingray has severe motor limitations due to the use of commercial ESC’s. Since the ESC’s we use are developed for RC use, they do not have very accurate speed control, and only controllable in one direction, which means there is a lot of untapped potential power in the Stingray’s existing configuration that we cannot access yet. This is compounded further by the fact that the motors have strict thermal limit, which limits the maximum power to 130W. Without a reliable method to detect current, the power limit is reduced further to ensure there is a safety margin, reducing the output power further.

For future generations of Epoxsea Inc. ROV's, we aim to develop our own brushless ESC to get finer control over the motors. To get better performance, we aim to integrate Field Orientated Control (FOC), which allows for better power output from the motor at increased efficiency when compared to existing ESC's. FOC uses a closed loop control system, to ensure that the induced electric field is always ahead of the 3 phases of the motor coil, which allows for more constant torque without wasting extra power. Since implementing FOC requires sensors to monitor the motor's speed, current and voltage, the data from the same sensors can be sent to the shore, which can then be used to create better control algorithms that improve the motor's performance and reduce the effort required to pilot the ROV.

Corporate Social Responsibility

Epoxsea Inc. has helped coordinate two workshops with the support of The Institution of Engineering and Technology Hong Kong, and RS Components Ltd. The workshops were organized to help local and international participants of the MATE ROV competition to design and build their ROV's. Our aim is to foster and develop skill sets and knowledge among secondary school students' to enable students to build their own ROVs. In addition to conducting workshops, ROV technology has been adapted for use in a social inclusion project organized by HKUST GCE with support from Epoxsea Inc. In March 2015, an Underwater Robot Competition was held, with support from The Institution of Engineering and Technology Hong Kong, and is sponsored by Louie Industrial Company Limited. The competition targets 20 teams of primary and secondary school students, both from mainstream schools and those students who are underprivileged, ethnic minorities and disabled. The objectives for the competition is to provide students with opportunities to understand the fun of Inclusion, Science, Technology, Engineering, Art, and Mathematics (iSTEAM), and to nurture social inclusion and develop understanding of the values and needs of students with different abilities and backgrounds. We were really pleased to use our engineering knowledge to serve the society and to see people of different backgrounds using our engineering technology to work together to build ROV's.

Figure 37: Underwater Robotics Social Inclusion Competition conducted by HKUST GCE and supported by Epoxsea Inc.

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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 2015.

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

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

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

Figure 38: Logos of the acknowledged parties