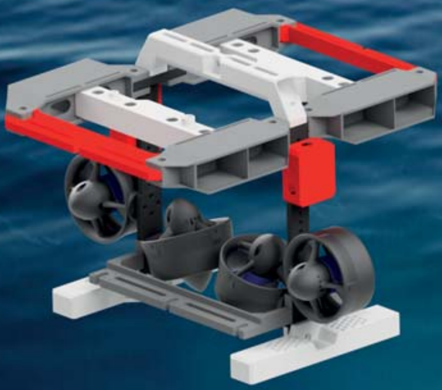
Macau Anglican College

Fish Logic

Blazin Hydra

Technical Report/2018



Members	Roles
Chan, Pou Hei Gavin	CEO, CTO
Chan, Yee Lam Cerys	CFO, QCO
Ho, Leng Chit Joshua	Electrical Engineer
Sin, Ka Iat Yorky	Pilot
Leong, Weng Sam Ada	Mechnical Engineer
Sin, Wai Teng Isaac	Mechnical Engineer

Mr Andy Tsui - Mentor

Macau SAR

FISH LOGIC
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Abstract

Blazin' Hydra (B'H) is Fish Logic's third Remotely Operated Vehicle (ROV), designed on the request for proposals by MATE Center and the Applied Physics Laboratory at the University of Washington. The request is for a ROV able to salvage wreckages, recover a seismometer and installing a tidal turbine and instrumentation to monitor the environment. To meet the desired functionalities, Fish Logic, a company dedicated to developing underwater ROVs, have designed B'H with a flexible configuration, able to adapt to the multiple tasks.

B'H is fully designed by the six dedicated members of Fish Logic. The design is a continuation of the previous year ROV's (Leviathan) design philosophies of modularity and standardization enabled by casting electronics in epoxy and 3D printing the structural parts, with the optimization for manipulators. The majority of B'H's structure is 3D printed allowing the structure to take on a very unconventional form that is modular and standardized. The structure supports four brushless thrusters and manipulators which can be "hot swapped". B'H was designed to meet strict size and weight restriction. The resulting ROV design has a flexible configuration, a small profile, and reliability optimized through simplicity.

The development period of the B'H encompasses an entire year with about a thousand work hours dedicated to it. The market materials value of the B'H is 10,577HKD.

Design Rationale

Design Philosophy

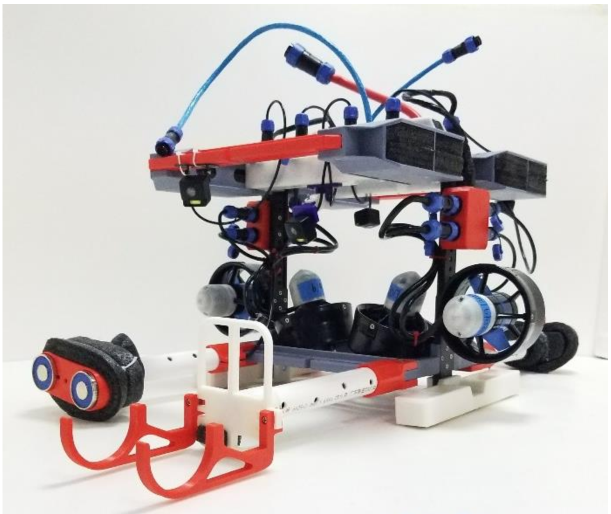


Figure 1 Complete Blazin' Hydra

The previous year's ROV, Leviathan, was a proven revolutionary solution with all electronics casted in epoxy, eliminating the usage of air filled canisters. B'H is a further refined, simplified and improved solution affirming the core philosophies of modularity, standardization, and manipulator oriented design and reliability through simplicity.

The modular system of the ROV has been further refined and simplified. Electronics on both the B'H and Leviathan are casted in epoxy to waterproof. This eliminates the waterproofing issues associated with an airtight canister; however it makes the electronics inaccessible. Having the electronic components housed in modules allows only faulty components to be replaced. Having multiple modules leads to another problem of having too many external connectors thus higher risk of water leakage, as well as increasing the difficulty of cable management. On B'H's electronic modules, power and signal connector are then combined to reduce the number of connectors, we name it Universal connectors.

Mechanical standardized by the Standard Mounting System (SMS2) allows any parts with SMS to be interchangeable so that the core ROV and the manipulator configuration is flexible. This allows a generic ROV to first be developed and then specialized later after the mission details are released. Since the Leviathan, SMS was introduced allowing modular components to be installed with 4 M3 screws. While the design generally worked, SMS2 has reduced it to require only one M5 screw to fasten. The SMS2 with a larger screw has a stronger mounting strength and with a much faster mounting and dismounting.

Electrical standardization is achieved with the Universal connectors which transfer power and I2C signal in one connector. I2C is a bus network which means modules can be connected anywhere in the network. This allows the connections to be interchangeable and simplifies the circuitry while improving safety. The electrical system is also scalable, new devices from small sensors to thrusters can be plugged in as easily as any other devices.

The control system was simplified by expanding the I2C network across the tether, eliminating the need for an onboard Master controller. For manipulator, electromagnets are used, which is the simplest active manipulator, for completing most of the tasks. Reliability through simplicity is achieved by considering its simplicity in every design decision, ensuring all features do not undermine the entire ROV's reliability.

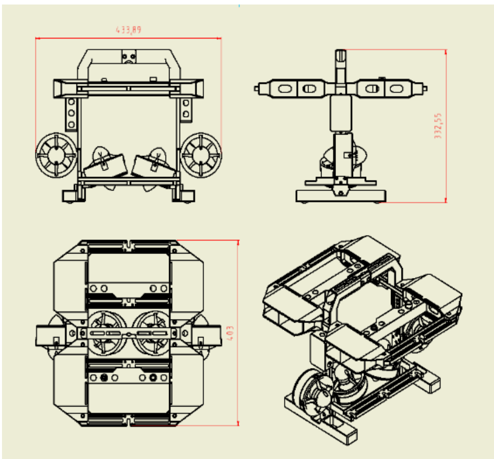


Figure 2 Blueprint of Blazin' Hydra

B'H design is also oriented around the manipulators. To provide maximum flexibility and space for the placements of the manipulators or other devices, the front and rear, top and bottom levels all have SMS2 mounting rails. The ROV can switch the direction of the driving profile between the front and rear to eliminate the difficulty of piloting with manipulators facing backwards.

Mechanical

Material Choice

Manufacturing Techniques	
3D printing	CNC
<u>Advantage</u> More efficient, only uses the amount material that makes up the object that it's printing Easy to print and operate Parts produced are light weight, ideal for ROV <u>Disadvantage</u> Slower, printing layer by layer takes hours for a small part. Limited material selections	<u>Advantage</u> Typically faster when doing large scales manufacturing Wider material choice <u>Disadvantage</u> Less efficient, uses more material. Process is much more expensive

Materials	**PLA**	**PLA+**	**ABS**	**XT (PETG)**	**Aluminum**	**Iron**
Density (g/cm³)	1.24	1.24	1.04	1.30	2.70	7.874
Elongation at break (%)	5	29	22	228	12	0.52
UTS (MPa)	73	60	43	49	276	275
Ease of Manufacturing	Easy to Print	Easy to print	Difficult to print. Warping, and toxic fume requiring a heated enclosure	Difficult to print. High heating temperature. Warping issues.	Difficult to mill. Lack of in house 3D milling machinery	Difficult to mill. Lack of in house 3D milling machinery

PLA+ from eSun is the material of choice for all 3D printed parts. The extensive use of 3D printing plays to our team's strength of fast paced innovation, giving us the ability to produce prototypes rapidly, testing our designs for improvement, thus boost the workflow. 3D printing allows parts to be designed with much less geometric restriction, than subtractive manufacturing.

PLA, used in Leviathan, is brittle. XT from colorFabb, is found to be too flexible for most structural parts and cracks easily (in contradiction to research), difficult to print due to warping and produce parts with low quality. PLA+ has the balance between the durability of XT while having PLA's ease to print and print quality. To provide extra structural strength epoxy is used for fill in the 3D printed parts.

SMS2

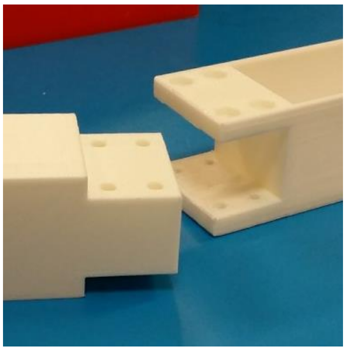


Figure 4 SMS of Leviathan

The Standard Mounting System (SMS) is the mounting system used in most parts of the ROV. The SMS2 in B'H is an improvement of the SMS from Leviathan. It is designed so that manipulators can quickly swapped and camera position can be easily changed, it's also used in core ROV components allowing the whole ROV to be easily transported and to reduce the risk of damage by disassembly.

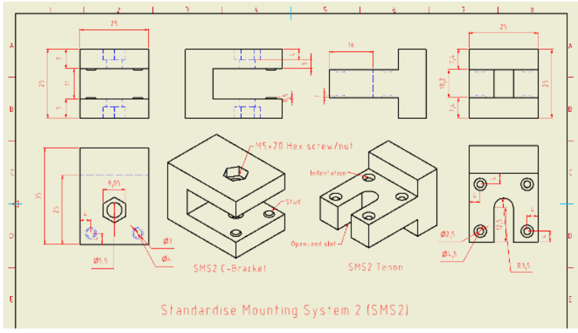


Figure 3 Blueprint of the SMS2

A SMS consists of a C-bracket and a tenon, the C-bracket of the SMS is to clamp onto the tenon and secured by a single M5 screw and nut. The use of one screw decreases the time needed to tighten screws compared to the 4 screws used in the SMS of the Leviathan, however, using only one screw may decrease the strength of the SMS, so M5 screws are used in SMS2 instead of M3. Nut traps integrated into the C clamp removes the need to use a wrench when securing the C-bracket. Nut traps on both sides of the C-bracket also gives the ability to insert the screw in both directions, giving the option to choose an optimized position for screw placement. This allows the team to reach all the screws directly without disassembling other parts of the ROV. Studs are added on the C-bracket to prevent rotations when mounted, reducing movement and resulting in a stronger mounting force. The tenon of the SMS is the counterpart to the C-bracket and its square design allows for mountings on any of the three orientations, giving more options for parts to be mounted. The SMS tenon could be converted into the form of a rail, allowing parts to be mounted anywhere on the rail and positioned precisely according to its needs. There are total of 4 rails in the ROV, an upper level and lower level on each side of the ROV, which give more space for mounting more tools, reducing the need to change tools due to lack of space. A slotted screw hole in the rails of the SMS allows the adjustment of position need for completely loosen or to remove screws.

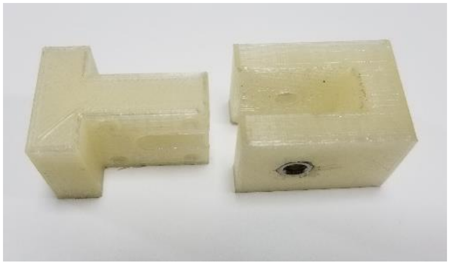


Figure 5 Prototype of SMS2

Buoyancy

An ideal ROV should only move in the direction the pilot commands and stay put in terms of translation and rotation by default. The center of gravity is kept low, while the center of lift is located high above it. The thrusters, ballast feet and manipulator which have the most weight are located at the bottom of the ROV to keep the center of gravity low. Having the manipulators placed low on the ROV provides an added benefit, where the manipulators can reach the props on the pool bed. The

Figure 6 Bottom view of the ballast feet

center of mass is located on the same plane as the thrusters, so the center of thrust will always align with the center of mass, which prevents the ROV from tilting.

Foam is used because it provides lift to compensate for the ROV's weight in water by decreasing the density of the ROV as a whole. Instead of airtight variable lift compartments, foam is used as it is relatively simpler to fabricate, and it does not have waterproofing issues. Foam is also more flexible as they can be cut into any shape and size to be placed anywhere, from the Foam Bars to the insides of PVC tubing. This flexibility allows the buoyancy of the ROV to be adjusted, since the amount of foam can be easily changed. Small pieces of foam are stored in chambers of the Foam Bars, which allows quick adjustment by hand for precise buoyancy balancing.

Figure 7 Float bar filled with foam

Figure 8 Universal Hub filled with foam balls before casting epoxy

The main purpose of the ballast feet is to support the ROV on land, meanwhile increasing the weight of the bottom of the ROV, improving its stability by lowering its center of mass. There are four heavy metal balls, which make up most of the weight of the feet. They allow B'H to roll on the pool bed.

Electronic modules which have been epoxied for waterproofing are often filled with foam spheres. This is to displace the epoxy, and reduces the mass of the module, hence its density. This allows those modules to be located on the upper level, without causing major upset to the balance between the center of gravity and the center of lift.

Propulsion

The ROV is propelled by 4 thrusters, 2 horizontal and 2 tilted vertical thrusters. This configuration allows the ROV to have lateral movements by having the vertical thrusters thrust in opposite directions, with the only trade off of not able to control pitching, which can be compensated by having a stable buoyancy system. The 4-thruster configuration was chosen as it is the configuration with the minimal number of thrusters, which leaves space for manipulators, and still maintaining the necessary degrees of freedom. Other configurations such as the 6 thruster vectored configuration offer higher maneuverability, however the ROV would be too bulky and the extra thrusters take up a large area for manipulator placements.

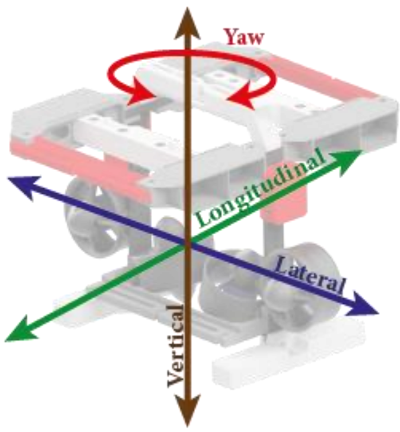


Figure 9 Four degree of freedoms (DOF)

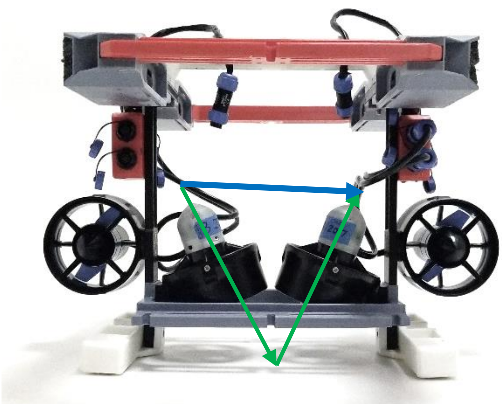


Figure 10 Thruster arrangement (front view), showing the resultant force of the lateral movements

The thrusters are T100 from BlueRobotics. They are selected as they are proven to be reliable, powerful (2.36kgf), compact compare to other similar commercial products; all while remaining affordable. The required skills to build thrusters of such quality, especially the propellers, far exceed our own capability. Therefore purchasing the T100 is the best solution.

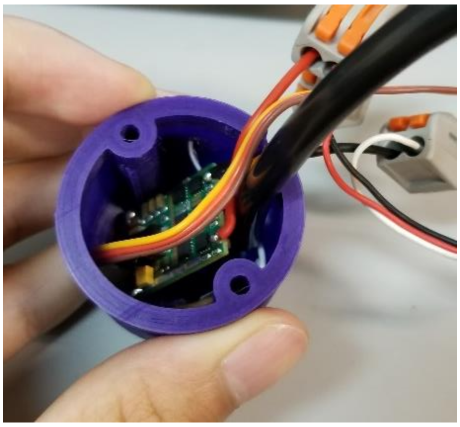


Figure 11 Early prototype of the ESC housing

The BlueESC that was previously integrated with the T100 thrusters is no longer available, likely due to technical issues. This forced us to fabricate our own ESC modules by waterproofing commercial ESCs (Afro 12A ESC) that support I2C. The replacement ESC modules were made to the same shape and size as the original ESC housing so as not to affect the original profile of the thruster. The new ESCs offer even more power than the previous ones. During water trials on last year's Leviathan, two T100 thrusters with BlueESC used on the Leviathan could not produce at least 3N of thrust, while similar configuration with the new ESCs can comfortably produce more than 5N.

Figure 12 Final ESC housing installed

Electronic

I2C

I2C is a BUS network that is used as the main communication protocol in the ROV, and it is a key component to achieve standardization. Although this type of network makes the electronic system and software more complicated, it allows all onboard components be connected anywhere on the same network, making B'H's configuration flexible, simplifying its circuitry, and assembly easier.

I2C was chosen over its alternatives mainly for the ease of use as well as its widespread support from hardware manufacturers of low cost electronics. Controller Area Network (CAN) is another BUS network used for real-time communications, however, it requires specialized, high performance and relatively bulky hardware. To be able to control devices that do not support I2C, a digispark (similar to a very small Arduino) is used to indirectly connect the device to the network. Although this increases complexity in the software and electrical systems, it is worthwhile as it provides the benefits mentioned above.

B'H's I2C network expands all the way across the tether to the Raspberry Pi 3 (RPi) in the control box which runs the control program. This is achieved by using two off-the-shelf I2C extenders at each end of the tether, which converts and transmit I2C signal over CAN bus. This extends the transmission range from 4m to 300m. I2C is converted to CAN bus, because it has the range of more than 1400m achieved by using differential signaling, which also allows the onboard electrical ground and ground of the control box to be different.

Since RPi provides on board hardware I2C, it is directly connected to the bus and the control program can run on it. Compared to using a laptop computer to host the control program, RPi can remove the need for extra USB-I2C converter, and the control system can be all integrated within the control box.

Connectors

For safety and convenience, any connector with the same number of pins is safe to be plugged together. This is accomplished by having only one type of connectors for all the single orientated connectors with the same number of pins.

Universal Connector

Universal connectors are used to connect thrusters, manipulators and sensors to the Universal hub as well as from the Universal hub to the Control Hub. The connectors that conduct both power and I2C signals are arranged in a 6 pin configuration. By combining power and signal pins together, it allows the amount of connectors used to be greatly reduced, which minimizes the probability of having waterproofing issues and the components sizes at the same time. To provide sufficient current throughput to the thrusters, 2 pairs of pins are used for power as 1 pair of pins is only rated at 5A.

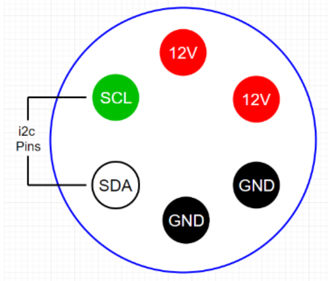


Figure 13 Universal connector pin definition

Tether Connectors

Tether connectors are used for connecting the Control hub and Camera hub to the signal tether cable. Since each hub only needs 4 pins, a 9 pin connector was used, where the upper 4 pins are connected to the Control hub, and the bottom 4 are for the Camera hub.

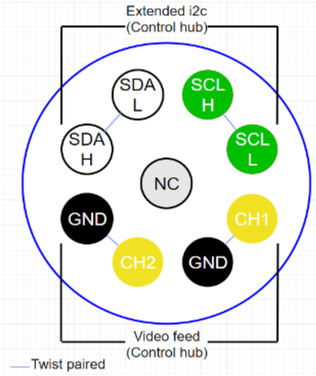


Figure 14 Tether connector pin definition

Universal Hub

As most onboard devices require both power and I2C signaling, plenty of Universal Connectors are needed. Universal Hubs acts like a household extension cords and power strip, distributing power, signal and connecting devices to the Control hub through its multiple connectors.

Camera System

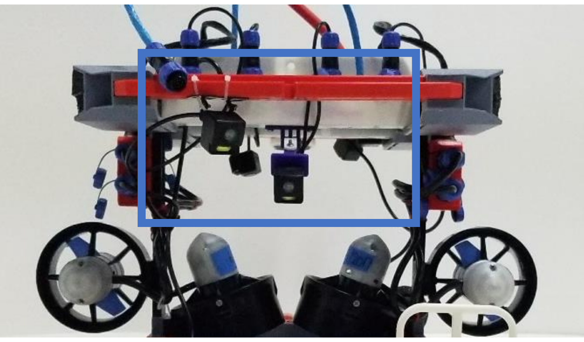


Figure 15 Front view of camera placement

B'H is equipped with 4 wide angle cameras. This provides two viewing angles for the front and the rear, with one optimally placed in the center pointed forwards, while the other is mounted on the side of the top layer providing a side view. These waterproof compact analogue cameras are selected as they offer minimal latency compared to digital cameras and has LED lightings integrated.

3D printed camera mounts allow the camera's orientation to be easily adjusted in terms of orientation and placement, with its dual rotational axis and ROV attachment parts. The mounts can be attached to the ROV's SMS rails, underneath the control hub or the camera hubs since they are interchangeable.

The cameras are connected to the Camera Hub, this enables the pilot to select between the 4 camera feeds on the gamepad, and to transmit the 2 selected feeds to the 2 monitors on the control box. This is accomplished with 2 camera switchers controlled by a digispark which is connected to the I2C network.

Control Box

The control box serves as a interface for the pilot. It is fitted with three monitors, two on the top of the box displaying the two video feeds from the camera hub and the one at the bottom displays the status of the ROV, all housed inside a protective splash proof case. Next to the status display is a modular system, inspired by server racks and cabinets, which houses the electrical circuitry of the control box, where each module has a

Figure 16 Control box with two monitors on top and one at the bottom. With the module racks on the right side,

specialized function. This system allows the electronics to be interchangeable and easily modified. Servicing the modules can also be done quickly as electronics are not mounted permanently to the protective case.

One of the module is fitted with an RPi, it is the main processor of the entire ROV system. The RPi is a powerful single-board computer that natively supports I2C, and it offers many I2C diagnostic tools, such as detecting the presence of I2C devices on the network. This eliminates the need for a laptop, which contains unnecessary programs, to run the control program, allowing time and space to be saved during setup.

Software

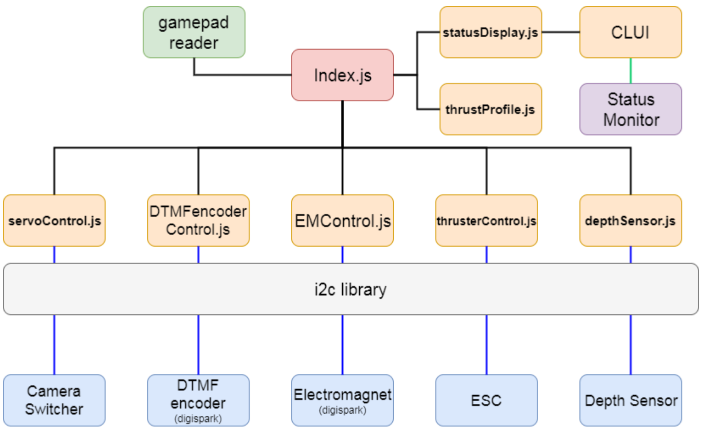


Figure 18 Block diagram of control program

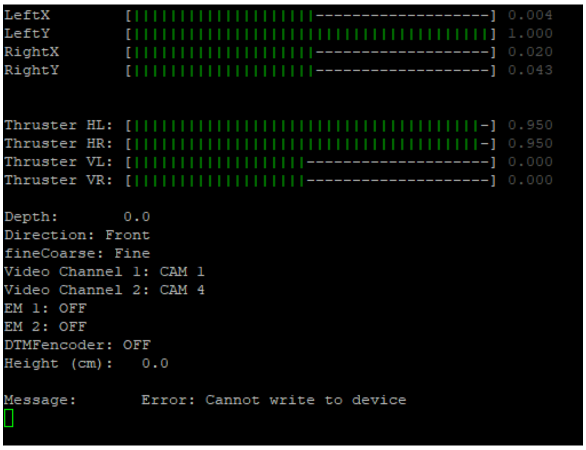


Figure 17 Status display of the control system

The control program is written in JavaScript. The decreased efficiency of a higher level program is negligible as the program is not very demanding. The program runs on an RPi using the node.js. With the program running on the shore side allows the program to be easily edited. Node.js uses an event-driven, non-blocking I/O model that makes it lightweight and efficient and it has one of the world's largest package ecosystem, npm, making libraries very accessible.

Each type of device has its own specific module, separating the different functions of the whole control and making them manageable. The modules are tested individually before integrating to the entire control program and tested together.

ThrustProfile.js maps the x, y coordinates from the gamepad to the thrust value for each individual thrusters. After the thrust values for each thrusters has been mapped, the values can be further adjusted to improve the performance. The values can be set to increase exponentially, making the region near the origin of the coordinates less sensitive and easier to make fine movements. The pilot can change the limiter of the thrusters between fine and coarse maneuvering on the gamepad. These settings can be easily tuned to suit the pilot's preference. The direction of piloting can also be switched between front and rear depending on where the manipulator is placed. This doubles the capacity for manipulator placement as they can be placed both in the front and rear.

The status of B'H is displayed on the monitor with command line interface (CLI). Having the status displayed greatly aids the pilot by reminding the pilot of the state of the ROV. It also greatly assists with debugging, especially with the thrustProfile.js. Using CLI to display requires minimal development effort compared graphical interfaces (GUI) however it restricts the interface to be extremely simple and plain. The status is displayed by using a hybrid between the CLI and GUI, CLUI, which displays the status in which is easier to comprehend fashion but without making the software far more complicated.

SID

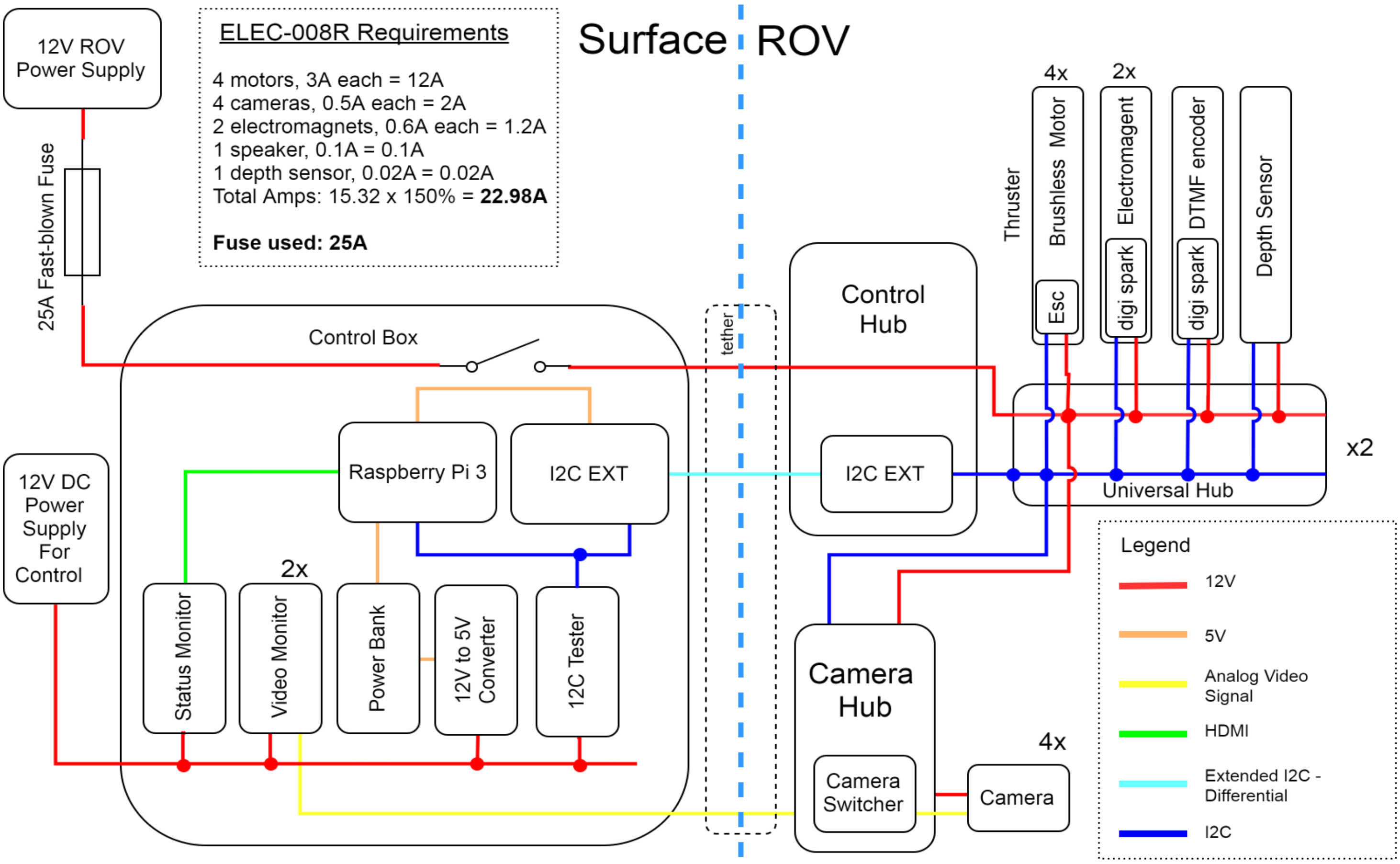


Figure 20 System Integrated Diagram (SID)

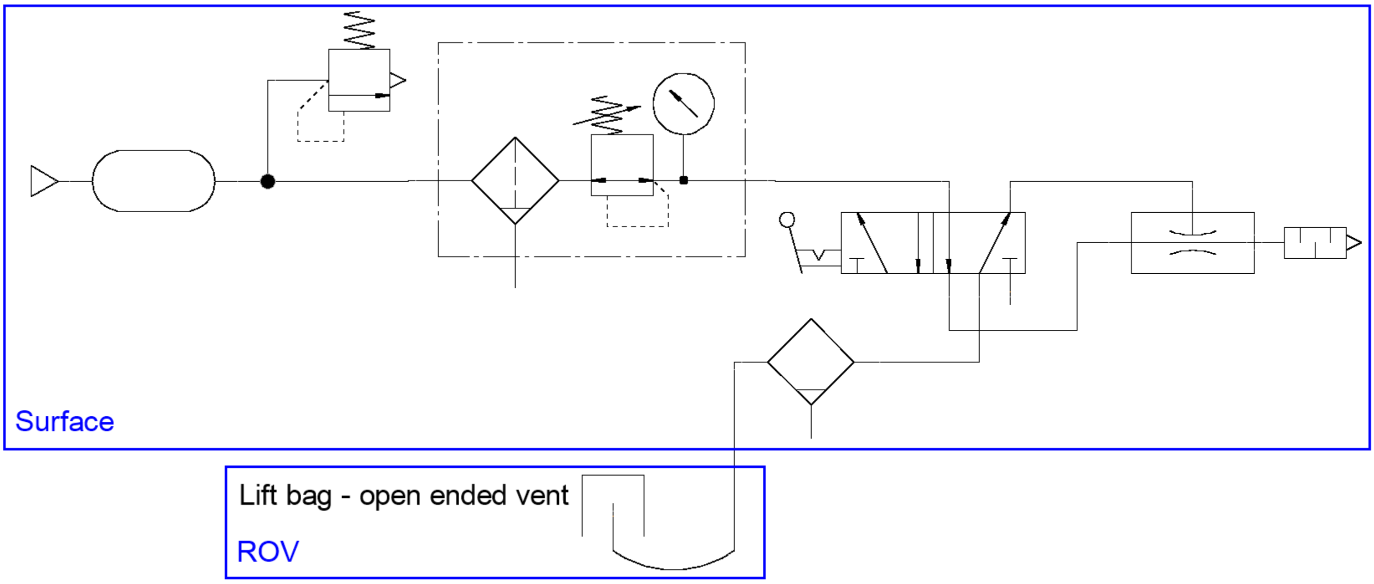


Figure 19 SID of pneumatic system

Mission Specifics

Figure 22 The Bi-electromagnet wrapped with foam

Bi-electromagnet

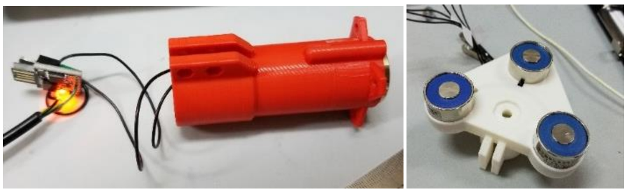


Figure 21 Initial prototypes of the electromagnet

The Bi-electromagnet is used for all 3 sets of tasks as it is capable of manipulating any magnetic material, including U-bolts or any magnetic surfaces that purposely placed it to be attached the magnet.

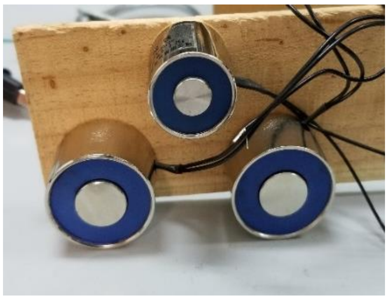


Figure 23 Testing electromagnets configurations on wooden plank

Although one 18kg electromagnets provides sufficient attraction on flat surfaces, the attraction is weak for U-bolts which has curved surfaces and hence small contact area. To solve this, 2 electromagnets are used to increase the contact area for a firm grip on the U-bolt. Additionally, a hook is installed between the magnets which catches the U-bolt if it is ever knocked off the electromagnet.

Electromagnets are reliable active manipulator compared to claws as they do not have any moving parts, making it easier to waterproof. The construction of the electromagnet solenoid circuitry, where the all wirings are originally insulated, makes waterproofing of the whole Bi-electromagnet module easier compared to waterproofing motors. Electromagnets also activates and deactivates instantly, whereas a claw requires a few seconds to grab objects, during which the ROV needs remain steady. Passive tools such as hooks, although being reliable as they do not suffer the issues associated with electronics, do not hold objects as securely since it relies on the weight of objects to hold them in place, which in comparison, is much weaker than the attraction force of magnets. Also, the design of passive tools are generally specialized for its tasks, compared to the versatility of an electromagnet active tool in a wide range of tasks. Passive tools often require fine maneuvering by the ROV to operate while magnets can hold onto objects simply by coming in contact.

Jet City Mission Helper (iOS app)

The team created an iOS app for the product demonstration in certain tasks. The app includes four functions, which allows the team to reduce the time spent on tasks that are not done by the ROV itself. The four functions include:

1. Calculating the vectors to locate the missing plane
2. Drawing the map after calculating the vectors
3. Searching the information of the plane by the tail ID entered
4. Calculating the energy generated on that day

The app was created with XCode, and is written in Objective-C. The app has a home screen that allows quick access to different interface of the tasks, depending on the task that the team would like to work on.

Other than calculating the ascent, descent and wind vectors, the app is able to draw the vectors on screen as well, this means that the vector drawn is very accurate, and it also saves time for the crew to do other tasks since the vector does not need to be drawn manually. Besides calculating the vectors, the app is also capable of calculating the maximum energy generated.

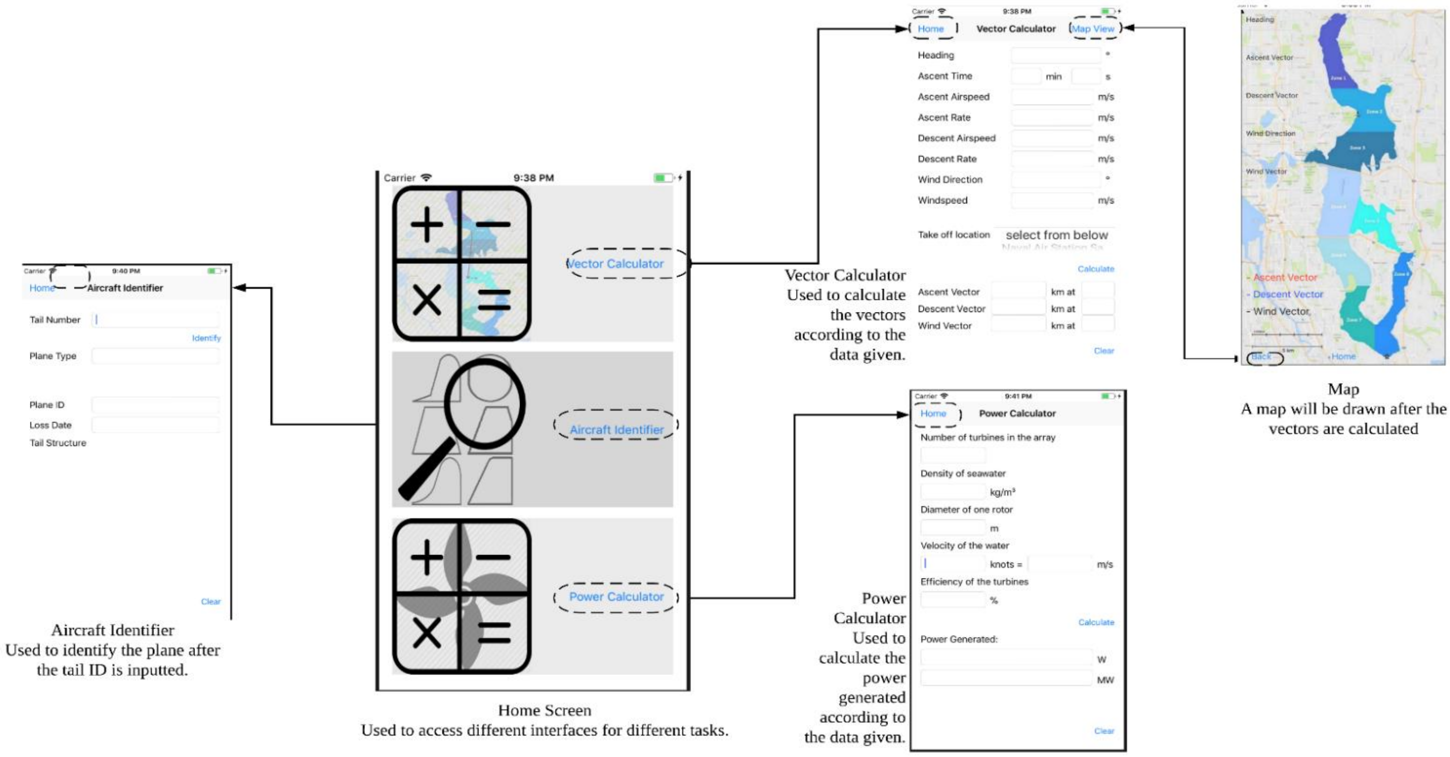


Figure 24 Storyboard for Jet City Mission Helper used for product demonstration

A dictionary resource was created to store the plane ID, plane type, tail ID, loss date and the tail structure. This means that when the pilot finds the tail structure and sees the tail ID, the team can identify it by entering the tail ID into the app, and the information of the plane will be displayed.

In the first draft of the app, the vectors were drawn by calculating the angle and the length, using trigonometric ratios. Although the vectors drawn were accurate and precise, it was difficult to draw the arrowheads. This is due to the lines being in different orientations, other than that absolute reference was used to map the points where the Bezier paths were to be drawn, which makes it more difficult to draw the arrow heads. Therefore, to solve the problem, transformation was used. First, a line representing the vector was drawn, with its length calculated by the vector calculator. Then it was scaled so that it would fit the map on screen, and then a triangle is drawn at the end of the line forming an arrow. In order for the arrow to be pointing to the correct direction, the arrows representing the ascent and descent vector were then rotated by the heading, whereas the wind vector was rotated by the direction the wind was blowing towards.

Aircraft – Lift bag

$$Volume\ of\ Sphere = \frac{4}{3}\pi r^3\ where\ r = 12.5cm$$

$$\Rightarrow Volume\ of\ Beach\ ball\ \approx 8100cm^3$$

Hydra has a detachable and deflatable lift bag system capable of having a lifting force up to 81N, allowing it to comfortably lift the 45N engine.

The lift bag system only consists of one lift bag rather than multiple bags in order to eliminate the need to reattach and retrieve multiple lift bags. Both inflation and suction are performed by a single compact air pump capable of fully inflating or deflating the bag under 30 seconds. All pneumatic operations are controlled by hardware and separate from main ROV control system. This makes the pneumatic system more reliable and safer than an integrated system, thus requires an extra crew other than the pilot to operate it.

Figure 25 Initial design of the lift bag

The internal structure of the lift bag spans from the bottom opening to the top of the lift bag, guiding the air hose to the top of the bag. It constrains the height of the flexible beach ball to ensure the hose remains at the top of the lift bag and prevent the rising water level from overflow into the air hose during deflation.

Figure 28 Final design of the lift bag

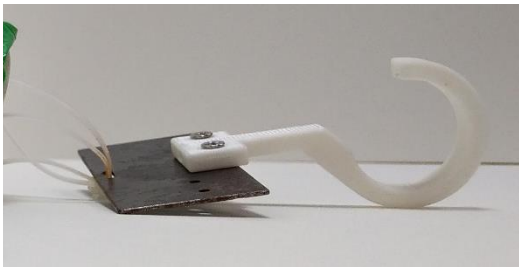


Figure 27 Lift bag hook reinforced with resin

Figure 26 Prototypes of the lift bag hook

The air hose is made of hard plastic to prevent it from collapsing due to high external water pressure.

The hook of the lift bag is designed with a geometry that ensures the center of lift of the lift bag and the center of weight of the payload are aligned in order to prevent inducing any torque that will cause the ROV to pitch. Due to the heavy loads the hook needs to withstand, it is made with composite materials of 3D printed PLA+ reinforced by epoxy. The 3D printed plastic defines the geometry of hook, which makes it easier to fabricate to the desired geometry to then have its structure strengthened with epoxy. The metal plate that joins the hook to the lift bag allows it to easily attach and detach from the Bi-electromagnet of the ROV.

The operation to recover the wreck engine begins by having the lift bag inflated to the point where the ROV is just able to move the debris off the engine. The pump is switched off once the debris is removed, the pneumatic system would be changed from inflation mode to deflation mode by pulling the lever of the directional control valve, this utilizes the compressed air flow to deflate the lift bag with the vacuum generator, allowing the ROV to unhook from the debris. All these procedures eliminate the need to detach the lift bag or require multiple lift bags. The lift bag will be attached to the engine once the debris has been cleared and inflated completely to be retrieved at the surface.

Earthquake - OBS

Release Mechanism

Dual-tone multi-frequency signaling (DTMF) is the acoustic signaling system used to send a passcode from ROV to the OBS to trigger the release mechanism. DTMF originates from the system that telephones use to communicate with the switching center by using the sound frequency, which is vital to our application. This enables the signal to be transmitted as sound through air or water. Acoustic signal with dual tones (mixture of two pure sine waves) allows the decoder to much easily distinguish signal from noise. Due to DTMF's widespread use and its decades long history, DTMF is reliable and its components are accessible and common.

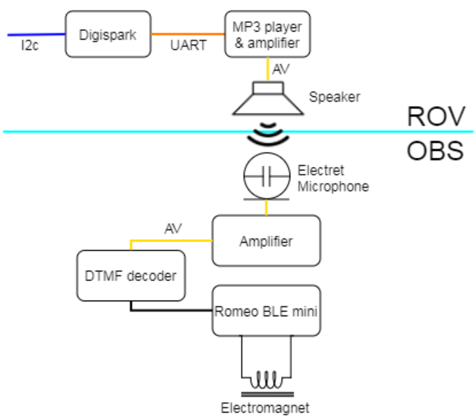


Figure 29 OBS block diagram

The encoder module of the DTMF system consists of a digispark which converts the I2C command to play the tones into the UART protocol specific to the MP3 player, where the tone (and other audio) files are stored. The MP3 player can operate a more powerful speaker and can produce higher quality sound, which makes decoding easier, than an Arduino paired with a small amplifier. An added benefit is that the MP3 player can play some random music for fun as a sort of Easter egg.

Figure 30 Complete OBS with the connector

The decoder system in the OBS body consists of a waterproof electret microphone with an amplifier board connected to the DTMF decoder module (MS8870) that feeds the decoded signal to the Romeo BLE Mini development board. The board is selected as it has motor controlling functionality for the electromagnet of the release mechanism. It also supports Bluetooth programmer which allows reprogram even after it has been casted in epoxy and also act as an alternative release mechanism when the DTMF is not working.

Figure 31 DTMF encoder module

The electromagnet at the bottom of the OBS body is attracted to the top metal disk of the anchor, which is turned off to release the OBS from the pool bed. In the unlikely case where the DTMF systems and the Bluetooth system malfunction, a metal pin can be pulled using the Bi-electromagnet to release the OBS.

Connector

The connector consists of a PVC tube with magnet housing rings. 6 neodymium magnets with ample amount of attraction are evenly distributed on the 12 side in each of the 3 ring so it could be omni-directionally attached to the holder plate. The ROV extracts the connector by attaching to the its metal back plate with the Bi-electromagnet.

Holder

The metal plate on the OBS allow the ROV to simply place the connector to magnetically attach on it securely. The connector can be attached anywhere, and in any direction on top of the holder due to the large surface area of the plate. This is far more secure than a purely mechanical holder, such as a basket, as it is only held in place by the connector's own weight in water and may get loose when the OBS is being retrieved.

Energy

Tidal and Eelgrass

The Tidal base hook is a passive tool specially designed to bring the Tidal base to the designated area by holding onto the latching mechanism of the Tidal base.

The Tidal Hook was originally designed to be a single piece structure, however since the exact tidal base parts are unavailable in our region, an adjustable hook design was chosen, where the hooks are secured on a guided rail with nuts and bolts. This allows more easier and fine adjustments according to the actual tidal base.

Figure 32 Tidal hook double as eelgrass retriever

The back plate is a large frame that prevents the tidal base from pivoting up and down, while being hollow to not completely block the camera view.

The inner hook, is originally intended to be only used to transport the tidal base, it turns out it is able to transport eelgrass as well. The larger outer hook has greater diameter to hold the eelgrass easier.

I-AMP

The I-AMP is handled by the Bi-electromagnet and locked into placed by using the front of the tidal base manipulator hooks to push the locking mechanism, which is similar to the tidal array and latching mechanism and therefore does not require tools specialized for it.

Mooring

A screen capture is used to determine the proper distance to place the mooring, by using the known length of the designated area frame as a measure unit. This simplifies the process for the pilot as it only requires the ROV to be facing the tidal designated area and held steady for an instance to take the screen capture. A backup measuring tape, with a loop to attach over the vertical PVC pipe on the corner of the designated area frame, can also be used to measure the distance if the screen capture ever fails.

Depth sensor (MS5803-14BA) measures the height difference between the mooring base and the attachment point. The sensor was selected over a tape measure as it has a depth resolution up to 1 cm, a much smaller profile and reliability.

Figure 33 ADV attached to mooring

ADV

The ADV has a specifically designed mount for attachment to the U-bolt on the mooring line. It holds on to the U-bolt with 2 pairs of magnets aligned to the shape of the U-bolt, allowing a firm attraction with the U-bolt. The ADV is held by the Bi-electromagnet, with a cover to prevent the Bi-electromagnet from accidentally attracting to the U-bolt or the chain of the mooring.

Fabrication

Each part of the ROV has its own fabrication protocol, guiding the process of each part to be soldered, assembled, tested and waterproofed. Every fully tested part would be labelled with a birth certificate, which includes the date and other details specific to the device, such as its I2C address.

One of the team's main concern is waterproofing, when building the ROV the team went through many trials and errors before the team could achieve the targeted outcome, and the team has come up with a few innovative ways in fabricating the components.

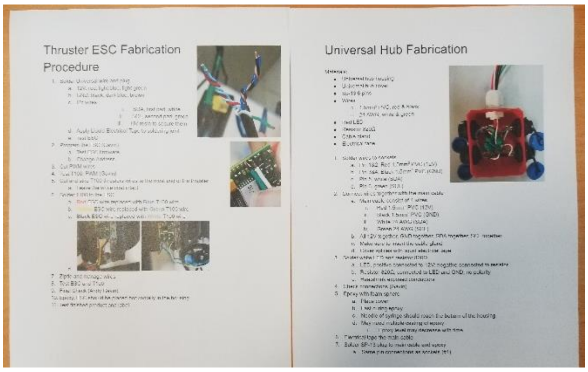


Figure 34 Fabrication protocol

Waterproofing of Plugs

Figure 35 Broken socket due to the corrosion by petroleum jelly

Based on the previous projects the team continued the method of injecting fast curing epoxy into the body of the plugs to fill in the gaps between the wires and the walls of the plugs, in order to prevent water from flowing into the plugs and getting in contact with the wires where it would cause damage. As the team identified that it is hard to fill up all the gaps without having epoxy flowing down the pins to the other end of the plug, where the connection of the plug and socket takes place, petroleum jelly was first used to fill up the connection end of the plug. However, the team soon found out that petroleum jelly was not the ideal method, as it turns out that it degrades plastic, which is what the plugs is mostly made out of. The team found a better alternative that does not corrode plastic, silicone grease. Alike the petroleum jelly used in the past, silicone grease is able to stop water from flowing in, since water and silicone grease is immiscible as well.

New VS Reused Components

Fish Logic, with its strive for continual innovation brings improvement to all aspects of the ROV. The decision on whether the parts should be reused depends on the new features, improvement in performance, effort needed to fabricate and financial cost of the components. This however means that almost all of B'H's components are new, as old parts can no longer be refurbished to be compatible with the new systems. An example is the introduction of Universal connectors, meaning that non-mission specific electrical components are not reused as the connector have changed with the power and signal pins combined.

In-house-built VS Commercial Components

Fish Logic fabricated in-house parts to achieve innovative and unique functional, parts that could not be commercially purchased. Performance of the components is then considered especially its reliability. Fish Logic fabrication capability is also considered on whether we can feasibly build the part ourselves. Devices with complicated functionalities, which exceeds Fish Logics fabrication capability, such as cameras, monitors and the gamepad are purchased. The cost of

With the many new components that Fish Logic aims to improve on, the team first research to check if they are commercially available. Parts, that fulfills the required specification are compared to the resources and skills required to fabricate it in-house. The features, performance, cost and especially reliability of the parts are extensively evaluated before purchase. When no suitable parts are available, then Fish Logic considers whether the team has the time, resources and the skills needed to fabricates them.

For the case of the thrusters, the commercial T100 thrusters have excellent performance, however the ESC that accompanies it have multiple technical issues. The original ESC modules were replaced with the in-house built ESC modules and integrated back onto the thrusters. This resulted with the thruster units with both the thruster and the ESC performing well.

Safety

Company Safety Philosophy

Safety precautions play an important role in every operation carried out by the team, as the team values the safety of all group members, the public and aquatic organisms. We ensure that all protection gears are used. All members are required to wear gloves, mask and safety goggles when handling dangerous and toxic chemicals, minimizing the risk of chemicals from getting in contact with any personnel.

Safety in Workshop

When soldering, it is essential for members to wear safety goggles and mask, preventing smoke from contacting the eye, or inhaled. Room tidiness is also important, working environment should be tidy to minimize accidents like trailing or wires and tripping over other tools and to prevent fire accidents. Members are required to wear a mask and gloves when handling resin or other adhesive chemicals, as it may cause burning or irritation on the skin. For operational safety protocol in lab and on deck please refer to Appendix 1: Operational and Safety Checklist.

Safety Features

To prevent accidents from occurring, a series of safety features are included on the ROV when designing. Due to safety reasons, if anything goes wrong within the control box and no command is sent to the thrusters within 3 seconds, the thrusters will stop moving. An algorithm was implemented into the system to prevent current spikes that could damage the electronics system. Other safety features include:

Safety Features	Description
Black and Yellow hazard labels	Black and yellow hazard labels are wrapped around the thrusters to remind people in the surrounding of danger and to not go near, to avoid cuts caused by the propellers when power is given.
Light	Light is installed on the ROV for it to be more noticeable in the surrounding to avoid accidents such as bumping into other ROVs, sea creatures or even divers.
Thruster Shrouds	Thruster shrouds are 3D printed and installed onto the thrusters, the shrouds are up to the standards of IP20 to prevent fingers from getting near the propellers, significantly reducing the chance of injury caused by the propellers.
No Sharp Edges	There are no sharp edges on the ROV, because all sharp edges are chamfered to avoid getting cuts and injuries.
Handle	There is a handle installed to the top of the ROV, this allows the ROV to be handled with only one hand, and it keeps all hazardous modules away.
Fast Blown Fuse	Fast blown fuses are used to cut the circuit when the current exceeds the designed limit. It is used to avoid accidents such as electric shock, due to the conduction through water by the exposure of wires or damage to the creature in water, which may result in death in the worse scenario.
Kill Switch	A kill switch is installed into the control box to cut the power in emergency situations.
Notification LED	There are notification LEDs installed onto different parts of the ROV to show that the ROV and the modules are powered.

Testing Protocol

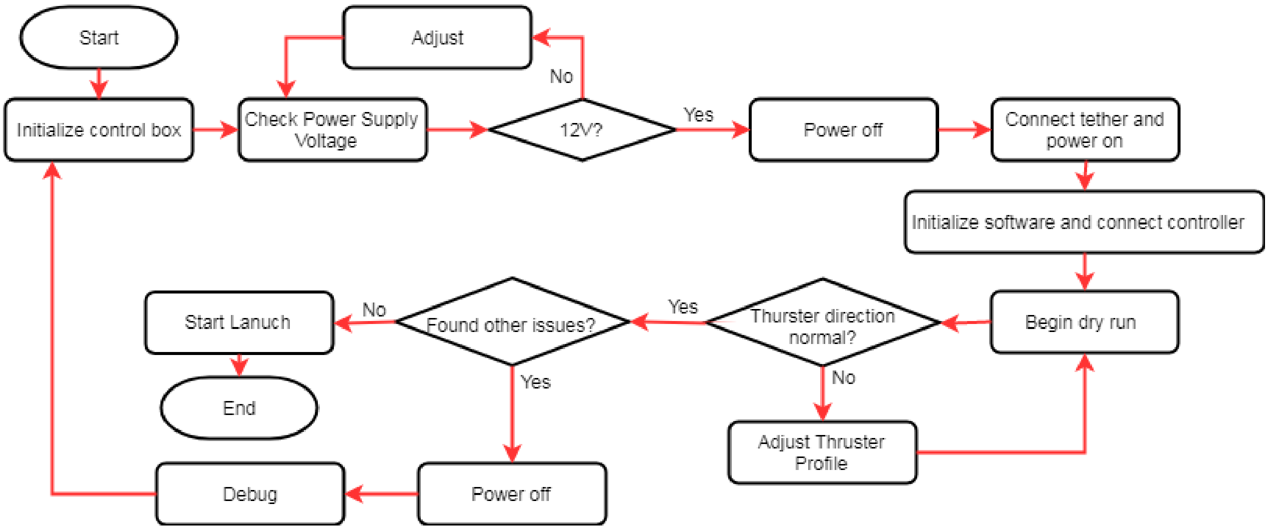
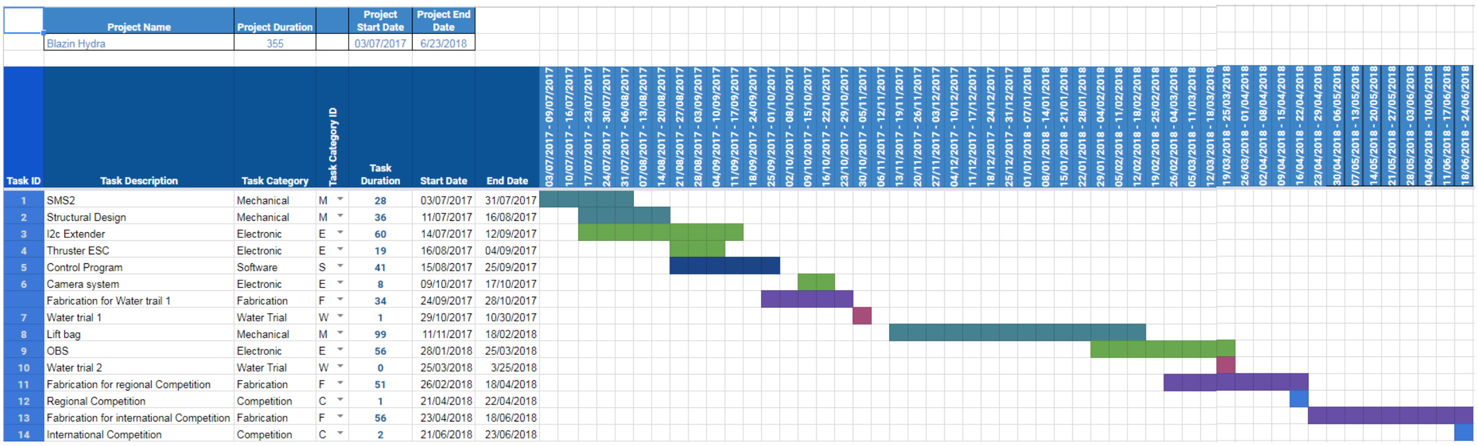


Figure 36 Flow chat of the testing protocol

Project Management



Project Name	Project Duration		Project Start Date	Project End Date
Blazin Hydra	355		03/07/2017	6/23/2018

Task ID	Task Description	Task Category	Task Category ID	Task Duration	Start Date	End Date
1	SMS2	Mechanical	M	28	03/07/2017	31/07/2017
2	Structural Design	Mechanical	M	36	11/07/2017	16/08/2017
3	I2c Extender	Electronic	E	60	14/07/2017	12/09/2017
4	Thruster ESC	Electronic	E	19	16/08/2017	04/09/2017
5	Control Program	Software	S	41	15/08/2017	25/09/2017
6	Camera system	Electronic	E	8	09/10/2017	17/10/2017
	Fabrication for Water trail 1	Fabrication	F	34	24/09/2017	28/10/2017
7	Water trial 1	Water Trial	W	1	29/10/2017	10/30/2017
8	Lift bag	Mechanical	M	99	11/11/2017	18/02/2018
9	OBS	Electronic	E	56	28/01/2018	25/03/2018
10	Water trial 2	Water Trial	W	0	25/03/2018	3/25/2018
11	Fabrication for regional Competition	Fabrication	F	51	26/02/2018	18/04/2018
12	Regional Competition	Competition	C	1	21/04/2018	22/04/2018
13	Fabrication for international Competition	Fabrication	F	56	23/04/2018	18/06/2018
14	International Competition	Competition	C	2	21/06/2018	23/06/2018

Figure 37 Gantt chart for the project

A year-long schedule was maintained throughout the development of the B'H. The first half was focused on developing the generic side of the ROV, with the development for the missions following immediately after the manual is released. This is in contrary to the Leviathan's (previous year) development, where work was still focused on the generic side of the ROV until February, leaving too little time for development on specialized manipulators.

Small individual tasks within each part of the schedule are then prioritized based on first how critical it is to the ROV to meet the milestones and then by its urgency. After considering those two sides, the team allocates members and resources to the task. Members' work allocation is based on their position, skills and interest in the task. Hence, most R&D tasks are completed by the CTO, while all fabrication tasks are managed by the QCO. When assigning tasks to members, they are told the due date of the task and what is depended on the completion of such task in order to motivate them.

To ensure the team maintains on schedule, every week, a meeting is held and the Engineering log is updated. The meeting allows the team to reflect on the week's progress and ensure that all members are aware of the current state of the ROV's development. The log records the design process and decisions taken on all aspects of the ROV. This makes it a great reference material with the added benefit of aiding the team to reflect on the progress while writing or when reviewing it.

Establishing a plan and proper measures ensured proper progress, and prevented any major last minute improvisation that could jeopardize the performance of the whole ROV.

Testing and Trouble shooting

Multiple water trials were conducted where the entire ROV and all its supporting system are tested. During water trials, the pilot gives feedback on the performance of the systems including the core control system and on how to tune the thrustProfile, the ease of use of the manipulators, and any external factors affecting the ROV. The status monitor aids in debugging the control program and in tuning the thrustProfile as well. The setup process provides insight into how the team can improve the system.

The Bi-electromagnet was first prototyped with using a wooden plank as a placement platform for the magnets. This is to test the strength of the different magnet configurations with metal plates and U-bolts. Two configurations were chosen for further testing, a two 18 kg electromagnet (Bi-electromagnet) and a three 6 kg electromagnet configuration, with their respective 3D printed housing designed for them. The 3 magnet configuration was better at attracting the U-bolt as the top magnet is better at preventing it from pivoting. However it is much weaker at attracting a horizontal metal plate such as the one of the lift bag, as the top magnet is not in use. Further precaution lead to the Bi-electromagnet configuration being fitted with a hook that prevents the U-bolt from falling off. The 2 large magnet configuration was ultimately chosen and proven to work well during the water trials.

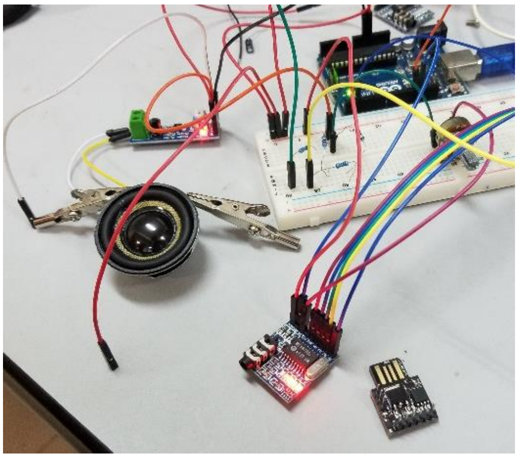


Figure 38 Breadboard testing DTMF module

In order to streamline the troubleshooting for I2C devices, the I2C tester in the control box enables devices to be tested independently and conveniently. It would be tested first to see if the device is detectable in the network, this would test whether the device is alive or not. After that then the main functionality of the device would be tested.

Research has shown that DTMF works well underwater. With that Fish Logic first tested DTMF in water with 2 smartphones, as the encoder and decoder. After the concept has been proven to work, tutorials was used to create a setup with basic electronics. Both the encoder and decoder side were tested individually with a smartphone before testing them with each other. They were tested with each other first without the speaker or microphone to make sure that the decoder can recognize the electric signal from the encoder. After confirmation of them working, the speaker and microphone were installed for final testing of the setup. Testing individual modules make troubleshooting easier by isolating the source of error. Once we have sufficient understanding

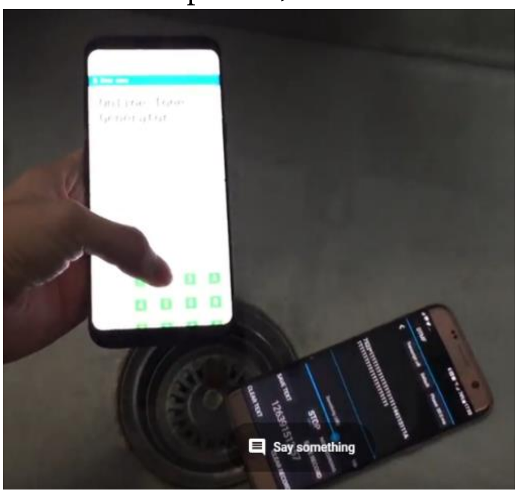


Figure 39 Testing the DTMF underwater

of the DTMF system, we then shift from making a bare minimum setup to developing a more optimized system. The Arduino was first complemented by an amplifier to boost its range but then ultimately replaced by a digispark and MP3 player due to its better performance and smaller profile.

Challenges

The development of the I2C extenders was particularly time consuming as the initial development approach failed, coupled with bad troubleshooting.

Originally the team planned to develop its own PCB for a PCA9600 I2C extender module due absence of such commercial product. A breadboard setup of the I2C circuitry was made, however it was never sufficiently reliable during testing. Nevertheless, the PCB was designed and outsourced for production as the team did not wish to give up on that approach with the effort already invested. The PCB was plagued with multiple critical errors and never worked.

Upon further research, the team found a commercial I2C extender utilizing differential signal technique and is likely to be far more reliable. The team also encountered problems when testing the extender due to the breaking of the solid core inside the insulation of a wire. Simple circuitry testing of the extender setup could not find the problem as the wire occasionally connects and disconnects. It took multiple days to locate the source of the problems before the testing setup worked reliably ever since.

Interpersonal

Due to the fact this school year is the critical in terms of university application for the senior members, a large amount of their time were allocated to studies and unavailable for robotics. To compensate for this, the time that can be allocated to B'H's development had to be made more efficient and productive by assigning individual roles that does not depend on others to be present.

As all of the senior members with experience from previous years will all graduate at 2019, the team has invested extra effort in developing new members to guarantee the future of the team. The best way to train new members is to allow them to work on the actual tasks, this however will lead to an inevitable drop in quality of work. To minimize the loss inequality experienced members guide, supervise and holds discussion with newcomers, while also improving them. Works produced by newcomers are checked more vigorously and are improved by senior members if needed. This takes a great amount of effort however it is worthwhile as the senior members also gain more experiences themselves by training others all while guaranteeing the future of the team.

Lessons Learnt

Technical

Lots of experience was gained from the development of the I2C extenders. Including the consequences of insufficient research, skipping development steps and ignoring signs of reliability issues. While prototyping the PCA9600 on breadboard, there were sign that reliability of the setup was not adequate, but the team decided to proceed on a custom PCB without further investigate the issue, which resulted in a failed product and wasted multiple weeks of effort. From then on, more effort was given to research and proof of concepts were tested more extensively while not ignoring any sign of abnormality before moving onto the next phase of development.

Interpersonal

While training junior members, Fish Logic realized that the capturing their interest is the most important factor. Large, long term goals have to be separated by shorter and smaller milestones or projects in order to keep their motivation with the sense of accomplishment. In addition, small projects teaches them the technical skills, which can be applied to the main project, as well as importance of meeting deadlines, responsibility and accountability.

Development of skills

Senior members have further refined their skills in 3D modeling, coding and fabrication. The programming team learnt about asynchronous task in JS and also creating app in Objective-C. Trainees are divided into smaller teams (mechanical, electronic and programming, media) to handle props, design and fabrication, which are co-mentor by senior members.

Future Improvements

The current sensory input for the pilot to work with is 2 monitors with 4 viewing angle and which the pilot's eyes can only focus on only one monitor at a time. To expand this narrow amount of sensory input, an audio system can be added to give the pilot a broader sense of the ROV's condition and surrounding. With recorded audio from an action camera on the ROV, the team concluded that the thruster's movements, whether the ROV has come into contact with objects or the activity of any sound producing devices like the DTMF encoder can be heard.

The onboard camera system can be fully decoupled from the other electrical systems by transmitting using video baluns that transmits differential signaling like the I2C extenders. This improve the quality of camera video with less noise and longer range.

Currently the only active tools on the Hydra are the electromagnets, enabling it to handle any magnetic objects. Soft robotic grippers can enable it to handle any objects, magnetic and nonmagnetic objects. Tentacles are versatile as they are flexible and its grip can adapt to the object's geometry and have a strong grip to lift heavy objects.

Finance

As the project commences at the end of the previous competition, a budget is prepared by the team with estimated expenses based on the expenses of the last ROV. The income is estimated approximately to the funding and is included into the budget plan. As a company with limited income, the team must stick to the budgeted expenditures. Whenever receipts are collected, it is entered in the project costing sheet and is compared against the budget to make sure that the capital is used properly and no extra capital is invested in unnecessary items. To keep the expenses low, the team would compare price of the parts that requires purchase in different stores, and choose the one with the optimum performance and lowest cost.

Every year our mentor writes a proposal based on our project budget to the FDCT, our main income source, to apply for the funding. FDCT has provided the team with a generous funding for our current project, the B'H, as well as our previous projects. Our secondary source of income is from our school, Macau Anglican College, they fund our accommodations and travelling fees to the regional competition in Hong Kong.

Another source of income is our parents, they provide us with financial support by funding our accommodations and travelling fees to the regional competition in Hong Kong.

Project Budget

Budget				
School Name:	Macau Anglican College	**Reporting Period:**	From:	03/07/2017
Instructor:	Mr Andy Tsui		To:	31/03/2017
Team Name:	Fish Logic			
Income				
Source				**Amount**
FDCT Grant				$ 12,000.00
Macau Anglican College Grant				$ 10,000.00
Expenses				
Category	**Type**	**Description/Examples**	**Projected Cost**	**Budgeted Value**
Hardware	Re-used	Joystick	$ (350.00)	-
Hardware	Re-used	Monitor	$ (780.00)	-
Travel	Purchased	Ferry tickets to Hong Kong	$ (2,800.00)	$ (2,800.00)
Travel	Purchased	Accommodation in Hong Kong	$ (10,000.00)	$ (10,000.00)
Hardware	Purchased	Waterproof plugs and general electrical components	$ (3,000.00)	$ (3,000.00)
Hardware	Purchased	Blue Robotics T100 thrusters	$ (3,840.00)	$ (3,840.00)
Hardware	Purchased	3D Printer filaments	$ (2,000.00)	$ (2,000.00)
Hardware	Purchased	General mechanical parts	$ (2,000.00)	$ (2,000.00)
Sensors	Purchased	Task specific sensors	$ (2,000.00)	$ (2,000.00)
Total Income				$ 22,000.00
Total Expenses				$ (26,770.00)
Total Expenses-Re-used/Donations				$ (1,130.00)
Total Fundraising Needed				$ (3,640.00)

(All currency in HKD)

Project Costing

Project Costing							
School Name:	**Macau Anglican College**				Reporting Period:	**From:**	**03/07/2017**
Instructor:	Andy Tsui					To:	31/03/2017
Team Name:	Fish Logic						
Date	**Type**	**Category**	**Expense**	**Description**	**Sources/Notes**	**Amount**	**Running Balance**
01/07/2017	Re-used	Electronics	Digi Spark and Arduinos	.	Leftover from last year	$ (400.00)	$ (400.00)
02/07/2017	Purchased	Hardware	Tether	Power, signal (CAT6) and air hose		$ (350.00)	$ (750.00)
03/07/2017	Purchased	Hardware	T100 Thrusters			$ (3,840.00)	$ (4,590.00)
15/07/2017	Cash Donated	Funds	-	Funds from Macau FDCT	Used for vehicle construction	$ 12,000.00	$ 7,410.00
10/08/2017	Purchased	Electronics	ESC	ESC for thrusters	Used for T100	$ (700.00)	$ 6,710.00
16/08/2017	Purchased	Hardware	Protective Box	Waterproof box	Used as control box	$ (260.00)	$ 6,450.00
16/08/2017	Parts donated	Electronics	Raspberry Pi		Donated by school	$ (250.00)	$ 6,200.00
16/08/2017	Re-used	Hardware	Joystick	PS4 console	For control box	$ (350.00)	$ 5,850.00
17/08/2017	Purchased	Hardware	Signal Wires		For ESC and Sensors	$ (250.00)	$ 5,600.00
17/08/2017	Purchased	Hardware	PVC	PVC pipes and tee	For props	$ (300.00)	$ 5,300.00
22/08/2017	Purchased	Hardware	Waterproof Plugs			$ (720.00)	$ 4,580.00
26/08/2017	Purchased	Electronics	I2C Extender		For control box and ROV	$ (180.00)	$ 4,400.00
13/09/2017	Purchased	Hardware	PLA+ filament	3D prints	For 3D printing	$ (1,030.00)	$ 3,370.00
15/09/2017	Purchased	Hardware	Camera			$ (340.00)	$ 3,030.00
20/09/2017	Re-used	Hardware	Monitor		Used in control box	$ (780.00)	$ 2,250.00
09/11/2017	Purchased	Electronics	Camera Switch		For camera system	$ (180.00)	$ 2,070.00
09/11/2017	Purchased	Hardware	Electromagnet		Payloads	$ (180.00)	$ 1,890.00
09/11/2017	Purchased	Hardware	Beach ball		Lift bag	$ (10.00)	$ 1,880.00
15/12/2017	Purchased	Electronics	Waterproof Speaker and Mic.		OBS	$ (70.00)	$ 1,810.00
15/12/2017	Purchased	Electronics	DTMF Decoder		OBS	$ (32.00)	$ 1,778.00
28/01/2018	Cash Donated	Funds	-	Funds from Macau Anglican College	Used for travelling and accommodation to Hong Kong	$ 10,000.00	$ 11,778.00
02/02/2018	Purchased	Electronics	Mic Preamp		OBS	$ (15.00)	$ 11,763.00
28/02/2018	Purchased	Travel	Accommodation	8 Beds x 2 nights' accommodation in hostel	For regional competition	$ (5,584.00)	$ 6,179.00
28/02/2018	Purchased	Electronics	Speaker Amplifier		OBS	$ (50.00)	$ 6,129.00
01/03/2018	Purchased	Sensors	MS5803 Module	Water pressure sensor	Mooring	$ (170.00)	$ 5,959.00
13/03/2018	Purchased	Hardware	Hand Pump		Lift bag	$ (120.00)	$ 5,839.00
20/04/2018	Purchased	Travel	Ferry	8 Round trips ferry tickets to Hong Kong	For regional competition	$ (2,800.00)	$ 3,039.00
07/05/2018	Cash Donated	Funds	-	Funds from Parents	Used for travelling and accommodation to the international competition	$ 140,000.00	$ 143,039.00
07/05/2018	Purchased	Travel	Flight	9 round trips to Seattle	For international competition	$ (56,160.00)	$ 86,879
07/05/2018	Purchased	Travel	Accommodation	11 nights in Seattle	For international competition	$ (78,478.00)	$ 8,401.00
Total raised							$ 162,000.00
Total spent							$ (153,599.00)
Final Balance							$ 8,401.00

(All currency in HKD)

Acknowledgement

MATE Centre – Sponsoring this year's competition.
IET- Hosting the regional competition.
FDCT – Generous donation of funding.
RS - Gold sponsors of regional competition
HK Electric - Silver sponsors of regional competition
CLP - Silver sponsors of regional competition
HKUST - Technical sponsors. Providing advice and hosting the briefing session of the region competition.
Macau Anglican College (MAC) – Funding our accommodations, and workshop space.
Mr. Andy - Our mentor for giving advice.
Ryan Chan - Our former team member, for providing advice and training new members.
Mr. Pong - Maths teacher of MAC for giving advice on the control program mapping algorithm.
Mr. Wilford – Physics teacher of MAC for giving advices on the electromagnets and other physical behavior.
Mr. Ryan - Lab assistant in MAC for assisting us in the experiments.
Mr. Carlos – Lab assistant in MAC for assisting us in the experiments.
Autodesk – Free student license software.
Our Families – Their continued support and encouragement.

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Appendix 1: Operational and Safety Checklist

In Lab:

- ☐ Safety gears are worn depending on the situation
- ☐ Area clear/safe (no tripping hazards, items in the way)
- ☐ Equipment are kept properly
- ☐ Keep the workshop tidy
- ☐ Make sure you have someone working with you

Soldering:

- ☐ Wear safety googles and mask
- ☐ Clear the table
- ☐ Turn on the ventilation

Handling Resin:

- ☐ Wear mask and gloves
- ☐ Turn on the ventilation
- ☐ Clear the table
- ☐ Prepare tissue paper

On deck:

Setting Up on Deck:

- ☐ Area clear/safe (no tripping hazards, items in the way)
- ☐ Tether is laid out and managed by a team member
- ☐ Plugs are filled and covered with silicone grease
- ☐ Plugs and sockets are connected securely
- ☐ Verify power switch is off
- ☐ Thrusters are properly shielded
- ☐ No exposed copper or bare wires
- ☐ Screws and nuts are tight
- ☐ Tether securely connected to ROV
- ☐ Single inline 25A fuse in place

Power-Up:

- ☐ Ensure team members are attentive
- ☐ Call out, "Power on"
- ☐ Power on
- ☐ Control computers up and running
- ☐ Call out, "Test thrusters"
- ☐ Perform thruster test
- ☐ Verify video feeds
- ☐ Test active manipulator

Launch:

- ☐ Call out, "prepare to launch"
- ☐ Deck crew members handling ROV call out, "Ready"
- ☐ Launch ROV

ROV Retrieval:

- ☐ Pilot calls out, "ROV surfacing"
- ☐ Deck crew calls out, "ROV on surface", when ROV reaches the surface
- ☐ Stop thrusters
- ☐ Remove ROV from water

Loss of Communication:

- ☐ Restart ROV
- ☐ Check status light
- ☐ Restart control program
- ☐ If communication restored, resume mission

Maintenance:

- ☐ Verify thrusters are free of foreign objects and are spinning freely
- ☐ Visual inspection for any damage
- ☐ All cables are neatly secured
- ☐ Screws and nuts are tight