FISH LOGIC

AMPHITRITE

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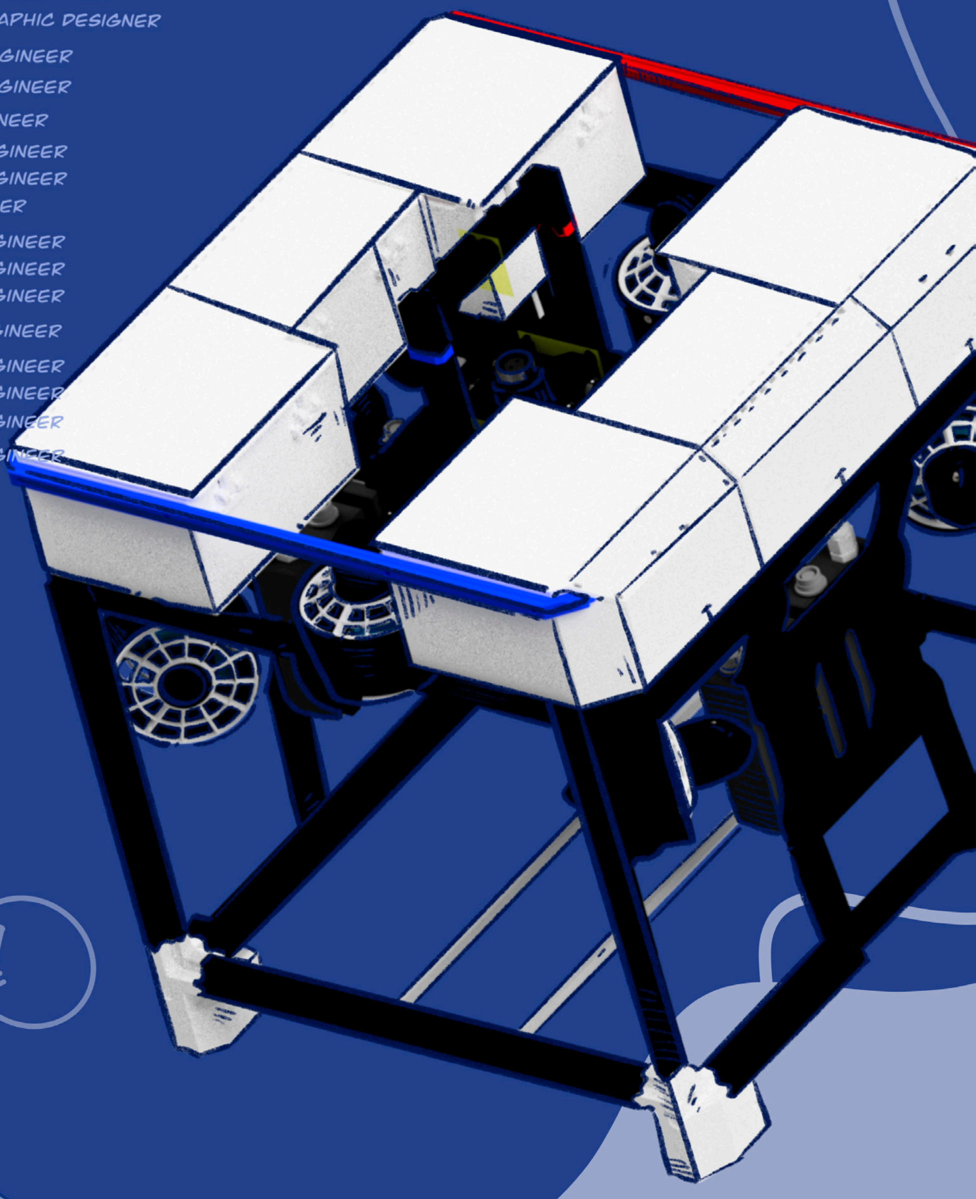

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Table of Content

Abstract

Fish Logic, a company based in Macau SAR dedicated to developing underwater ROVs, has designed and produced its eighth Remotely Operated Vehicle (ROV) - Amphitrite, of which was developed following the request for proposals by MATE Center and our wider global community for an ROV to assist in monitoring ocean conditions and investigating underwater ecosystems. To meet the desired functionalities, Fish Logic has designed Amphitrite with a flexible configuration. Amphitrite is capable of relocating ocean-observing assets and gathering data, connecting undersea cables, maintaining the coral reef ecosystem, and deploying GO-BGC Floats to monitor ocean conditions.

Amphitrite was fully designed by the 29 dedicated members of Fish Logic, and is an evolution of Fish Logic's previous ROV - Siren. It was made with an emphasis on the prioritization of safety and functionality, closely followed by not only ease of use, but also ease of maintenance and manufacturing. Fish Logic has incorporated systems engineering in designing the ROV for better system integration with all aspects of the ROV validated through testing to ensure our standards have been met.

The majority of Amphitrite's structure is 3D printed, allowing the structure to take on a very unconventional form that is modular and standardized. The structure supports six brushless thrusters and tools which can be "hot swapped". In addition, Amphitrite was designed to meet size and weight restrictions, with the resulting ROV being a high performance, flexible, reliable, pilot optimized and mission oriented vehicle.

The development period of Amphitrite encompasses 8 months with about 6640 work hours. The market value of Amphitrite is 4178 USD.

Figure 1. Members of Fish Logic with Amphitrite (Photo by Aiden Leong)

Front Row: Elanna, Kayu, Hinz, Jeff, Nathan Wong, Nathan Lip
Middle Row: Grace, Elli, Aiden Leong, Adrien, Marcus, Tin Nam, Veronica, Vienna, Hinrich, Doris
Back Row: Mr Ryan Ip, Mickey, Gema, Owen, Matthew, Edison, Yuuki, Desmond, Aiden Iam, Wyatt, Mr Kevin, Mr Ryan Chan

Project Management

At Fish Logic we firmly believe that the key components are having a flexible and collaborative management style. Therefore, Fish Logic adopts agile project management as it allows for continuous incremental iteration throughout the ROV development and the goal to achieve a working product as soon as possible to allow immediate feedback to be given through the development of the ROV and collaborative decision making. Agile allows our team to embrace a comprehensive vision set forth at the beginning of all of the development process, enabling flexibility and continuous improvement throughout the development phases. This approach allows Fish Logic the necessary space to readily adapt to changing conditions. As the development of the ROV advances, the team gradually refined their focus on the target with greater clarity. Agile methodology which emphasizes on regular feedback and collaborative decision-making, aligns well with Fish Logic's work culture.

Fish Logic chose Scrum as our Agile project management methodology because it allows the team to work in sprints within 2 to 4 weeks. Scrum divides the year development period and plots it into a release planning timeline with the length of each sprint preferably set so that each sprint ends on an event, such as an experiment date, system test date, or water test date, as it always requires deliverables such as a prototype part, tool, modifications or software release to become completed.

Scrum uses 4 types of documents known as artifacts: release planning, product backlog, sprint backlog and burndown chart. The product backlog is a priority list of deliverables that covers the entire scope of the project that the team needs to achieve for each sprint. Next, the sprint backlog is a priority list developed at the start of each sprint of all the tasks we need to complete in the current sprint. Fish Logic adopted Jira, a proprietary agile management software, it allows team members to view the current progress of the sprint, and the backlog of tasks yet to be completed before the sprint ends, as well as access to update the progress of their tasks. Previously, other team members were unable to contribute to the list/documents because both lists were written in Notability. Additionally, progress reports were slow because they were manually entered, therefore, Notability was abandoned. Jira also automatically generates a burndown chart and cumulative flow diagram of all the deliverables, which shows the overall progress of the project. In this situation, the CEO is referred to as the Scrum Master as they select tasks from the sprint backlog and briefs the team in a daily stand-up. Any obstacles to upcoming tasks were also discussed and dealt with. Scrum has enabled Fish Logic's ability to remain adaptable as schedules were often modified due to unknown water testing dates, academic work of the team members, public exams and unforeseen changes in the school calendar.

After the end of each sprint, we conduct a sprint review to gather all data from water testing which includes: video footage, software bugs and feedback from the pilot. Afterwards, during a debrief meeting, the data is used to analyze problems that we need to address, discuss the completed tasks and what work remains uncompleted. Then we conduct a sprint retrospective to inspect the working approach of the team, and look for improvements in our work method for the next sprint.

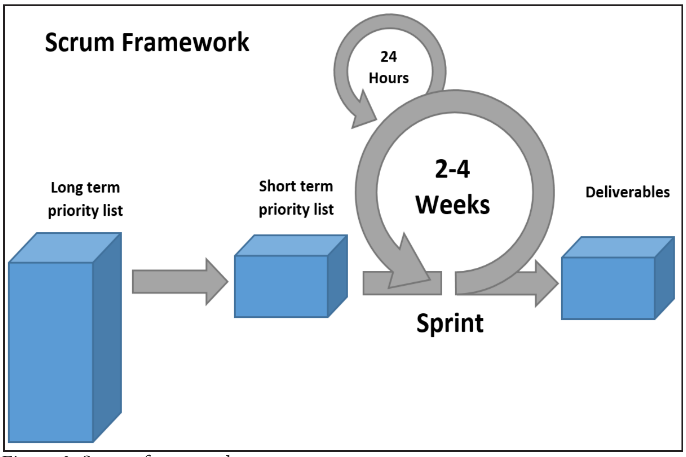

Figure 2. Scrum framework

Regarding the resources, it is easy to lose evaluation of resources allocated for the project as Scrum Agile management is less structured. However, by following the resource management principle of promoting the transparency of resources to other potential users in the team, Fish Logic can keep track of the purchasing and allocation of materials. A spreadsheet is used to track resources of each sprint cycle with special indication for resources that extend through more than one sprint cycle. Since Scrum uses rapid iterations in development, instead of committing to purchasing large amounts of resources as there may be changes in development direction, purchase decisions are executed only when initial test results justify committing resources needed for the next iteration in the purchase list.

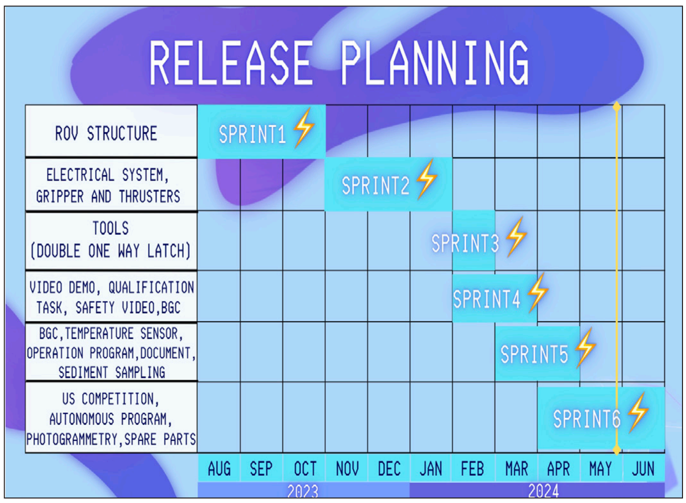

Figure 3. Release planning

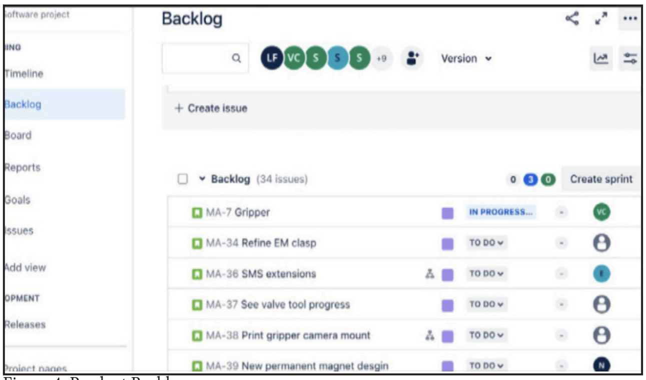

Figure 4. Product Backlog

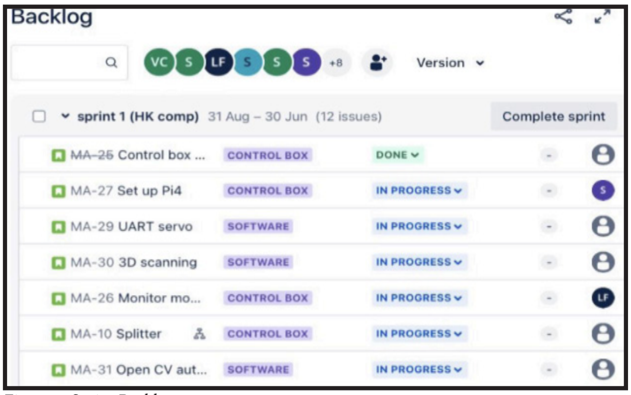

Figure 5. Sprint Backlog

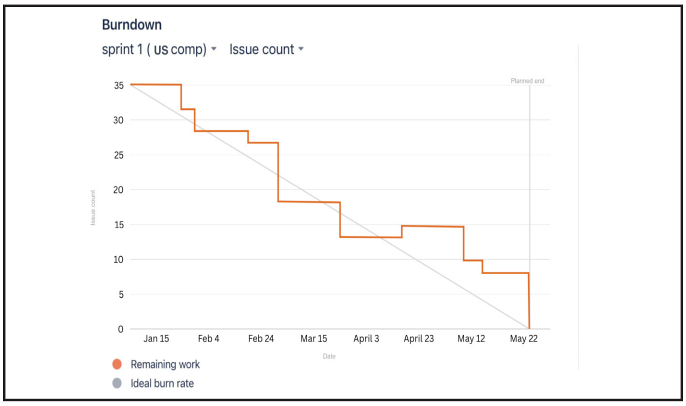

Figure 6. Burn down chart

Design Rationale

Design Evolution

Fish Logic continues to improve on and use many of the features and design principles carried on from previous years which were established ranging back from the ROVs: Leviathan (2017), Blazin' Hydra (2018), Electro Stargazer (2019), Hydron (2021), Otodus (2022) and Siren (2023). The principles are as follows: Safety, Functionality, Pilot Oriented Design, Ease of Use, Ease of Maintenance, and Ease of Manufacture, with all aspects of the ROV validated through testing.

Firstly, safety for personnel, wildlife and the environment is Fish Logic's number one priority. Functionality is evaluated by the ability to perform all mission tasks in the allocated time. As Fish Logic places heavy emphasis on pilot oriented design, factors such as good visibility, individualized control schemes, and custom set-ups based on pilot preference and feedback have shown increases the speed, accuracy, and consistency of the pilot in completing the mission. Ease of use prioritizes ROV stability, predictability, and corrective thrust vectoring and thus improves the confidence of the pilot. Ease of maintenance reduces the amount of downtime from swapping tools and allows for a quick return to water during operation. This is ensured by focusing on reliability, standardization, and modular parts. For mechanical reliability, simpler, passive design options are favored over active tools. However, active tools are used for tasks which require higher precision motion. The Standard Mounting System (SMS5), which is integrated into the ROV structure, allows any tools and payload with SMS5 to be interchangeable. Front-to-back symmetry of the ROV allows the ROV to carry double the payload on both ends, reducing the need for surfacing and increasing efficiency. Electrical standardization is achieved with the Universal connectors and CAN bus. CAN bus is a bus network in which modules can be connected from anywhere in the network, allowing the ROV to have a flexible and scalable configuration. Interdependent electronics are housed in the same module to minimize the interface between modules and simplify maintenance. Electrical components are cast in epoxy to eliminate all points of water entry, thus ensuring reliability. To achieve ease of manufacture, 3D printing is used extensively, which guarantees that all of the manufactured parts are of consistent quality and frees up team members to focus on the design of new parts while current parts are fabricated.

Fish Logic relies on the design principles to eliminate risk of technical debt build up during the design phase. Once a part is produced, the design will not only go through validation with data driven, scientific processes but also subjective pilot and operation team feedback.

In order to take on a more comprehensive approach, Fish Logic decided to fully utilize systems engineering principles in designing the ROV for better system integration. Fish Logic designs ROV tool layouts and the mission program in conjunction with each other and according to pilot preferences, which optimizes the approach to each task while minimizing the negative impacts towards other tools on the ROV.

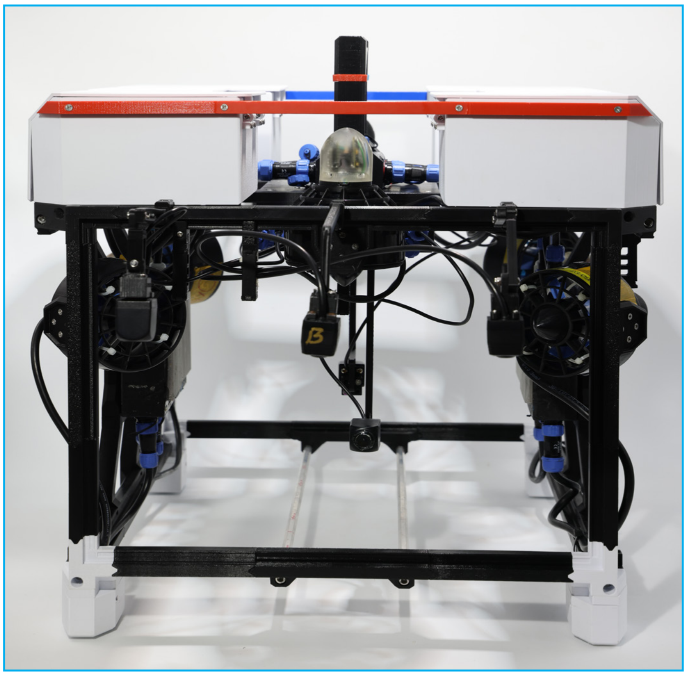

Figure 7. Photo of Amphitrite

Systems Engineering

Inspired by SpaceX and NASA, Fish Logic incorporates System Engineering into our project management due to its compatibility with Scrum Agile project management. Systems Engineering allows Fish logic to encompass the systematic and interdisciplinary approach to the development of a safe, reliable and well integrated systems in accordance with our 6 design principles by identifying and solving problems ahead of time in which Scrum also emphasizes on. This requires the important balance between intense preplanned system engineering and rapid prototyping to incorporate risk management, this balance heavily depends on the organizational agility, cost or iteration and ability to trade lower level requirements. Our team strives to learn by promoting iterative designs to learn through experience rather than consuming schedules attempting to anticipate all possible system interaction at once. By promoting better systems integration, system level tasks are distributed to different departments to allow them to focus on systems thinking. These are then reviewed by the CTO who is responsible for the role of an overall systems integrator. Only top level requirements are defined, tracked and verified but everything below these requirements is constantly traded and optimized during the design phases. This allows the prevention of derived requirements established in prior meetings from limiting the creativity of new ideas and solutions.

Fish Logic applies a systematic process for each tool during development. Once initial prototypes of tools enter the testing phase, the components' interactions with the rest of the system are considered. Before tool development, the ROV cameras had their field of view and minimum focus distance measured. Once the distance is established, since the main camera is located in the center of the ROV, new tool placements and lengths are adjusted to the set distance. Tools that require precision will have dedicated secondary cameras provided for complimentary camera angles. Interactions with other tools are studied once tool placement and camera angles are set. With tools mainly placed at either side in the front and back of the ROV, tools on the other side are carefully selected to minimize the interference between each other. Once all functional, pilot preferences and ease of use issues are addressed, and the tool design is optimized for manufacturing. Constant referral to the ROV tool layout and mission program helps optimize components and reduce unwanted impacts to the rest of the system. Such reviews also help identify parts that should be standardized and made modular. When necessary, ROV tool layout and mission programs can even be modified if advantageous.

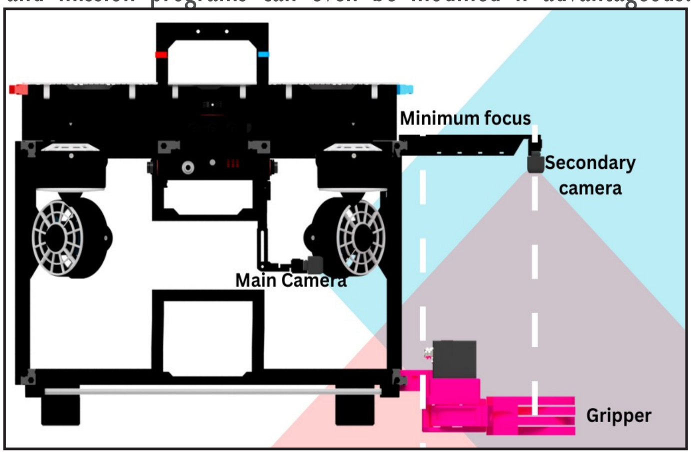

Figure 8. ROV Systematic process for tool development

Innovation

Simulator

Over the years, Fish Logic rarely had access to a pool to fully test the capabilities of the ROV. This bottlenecks the entire development sprint cycle, as much of the design and systems could only be validated on the pool access date. The pilot also has very limited run time to get familiar with the ROV. Due to these reasons, Fish Logic has used a ROV simulator created in Unity to aid in solving these problems.

The simulator approximates drag on the ROV by using the triangular mesh of a 3D model of the ROV to calculate the projected area in the direction the ROV is facing. A separate script converts the controller inputs into thrust vectors on each thruster that contributes to the movement of the virtual ROV. Buoyancy is simulated with the calculated volume of the

3D model and known density of the ROV parts. The combination provides an approximate physics model with adequate accuracy that can evaluate the performance of the ROV. For the pilot, in addition to getting accustomed to the controls, the simulator has allowed the pilot to test and propose new custom control schemes and tweak ROV speed profiles. The operations team including the pilot can also run through many different scenarios in the simulated missions to gain more experience in adapting to changes in the situation. By utilizing the simulator, estimated travel time of the ROV between tasks can be recorded. Such data has been taken into consideration when designing the mission program and the tool layout for the ROV to maximize efficiency during the missions.

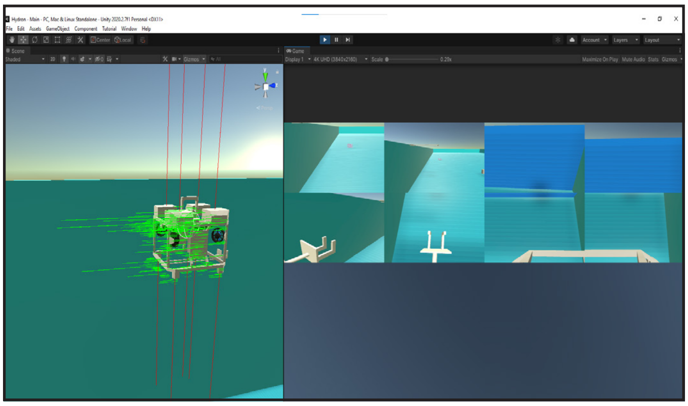

Figure 9. ROV Simulator of Amphitrite

Gripper

The fourth-generation gripper, Gripper V4, is a general-purpose tool with a multipurpose grip face, used to transport vertical profiling floats, transplanting branching coral and brain coral, deploy the irrigation system, and retrieve vertical ½ inch PVC while simultaneously used for various tasks at the discretion of the pilot.

One of the significant challenges encountered during the design process was selecting the appropriate material for the grip face. The team opted for elastic materials for the grip face due to their adaptability and higher friction. These materials can conform to the shape of various irregular objects, providing a better grip than rigid materials. As our ROV handles objects of different shapes and sizes, adaptability provided by elastic materials is crucial. Additionally, since the selected elastic material produces more friction than their rigid counterparts, it ensures that the object remains secured in the gripper without slippage.

Previously, we had used silicon rubber to construct our old grip-face due to its elastic properties. However, it would wear off due to the movement of the objects when the gripper was enclosed. Our team found that the main issue with silicone was that it was too elastic for our use case, as objects in the gripper often moved in the gripper. Over time, the silicon, which lacked durability, started to peel off from the gripper jaw.

To address this concern and enhance the longevity of the grip face, we have opted to utilize Thermoplastic Polyurethane (TPU 95A) filament for a 3D-printed grip face design. This material selection was driven by its superior durability and resistance to wear making it a more suitable choice for our application. Moreover, it was easier to manufacture since it no longer required hours of silicon preparation to make the grip faces. The material chosen for the main body of the gripper is the same PLA+ (polylactic acid) material as the rest of the ROV because of its proven print quality and strength-to-weight ratio.

The Gripper V4 uses a high torque 3.5 Nm ROVMaker waterproof servo motor, selected for its extra thick reinforced steel teeth, which have a depth rating of 300 m and a 360° rotational range. This servo drives the right jaw, which interlocks with and drives the left jaw at a 1:1 gear ratio to create a clawing motion. The Gripper V4 was designed to have a grip-face, grabbing objects extending to a maximum diameter of 90 mm, such as our vertical profiling float.

The opening and closing speeds of the jaws of the gripper V4 are 46.7°/s and could open up to 70°, giving it a maximum distance of 130 mm between the tips of each jaw.

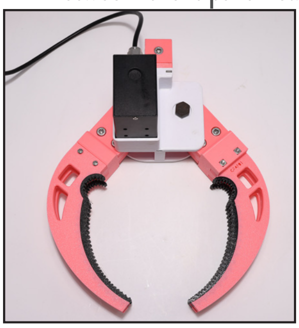

Figure 10. Gripper Opened

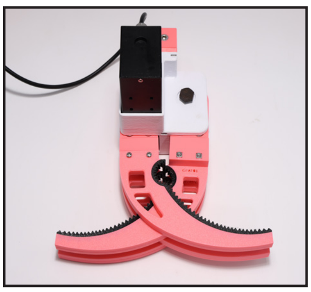

Figure 11. Gripper Closed

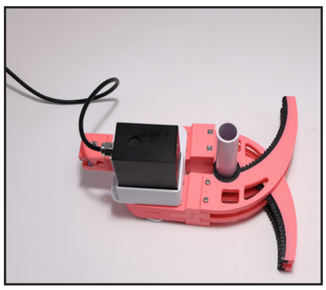

Figure 12. Gripper Closed (rotated-view)

Mechanical

Propulsion and Vehicle Dynamics

We have found that the baseline requirements of an ROV are established by examining all the mission tasks and the performance needed to complete all mission tasks within the provided time through years of competition experience. Thus, we determined that the ROV required 5 degrees of freedom (DOF) and a minimum movement speed of 0.6 m/s in all directions.

To achieve the first 3 degrees of freedom, which are drive, strafe and yaw, mounted on the 4 corners of Amphitrite are four T200 Blue Robotics thrusters on a 45 degree steering angle that exert forces in the horizontal plane, allowing for horizontal translations and rotations. 2 Blue Robotics T200 acts as vertical thrusters for vertical movement and pitching, with a rated combined lifting force of 56 N. The ROV has a recorded maximum speed of 0.63 m/s in all directions. To determine the center of thrust of Amphitrite, factors, for example, the center of mass and where drag is exerted on the ROV had to be accounted for. Instead of creating complex simulations, Fish Logic decided that the most accurate solution to determine the center of thrust was in the real-world environment. Therefore, we temporarily integrated adjustable thruster mounts so that the team members could tune and adjust the height of the horizontal thrusters until the ROV moved smoothly and met the pilot's preferences. The height of the thrusters is then measured with fixed thruster mounts created to avoid the need for tuning during every water test or product demonstration, reducing significant time consumption.

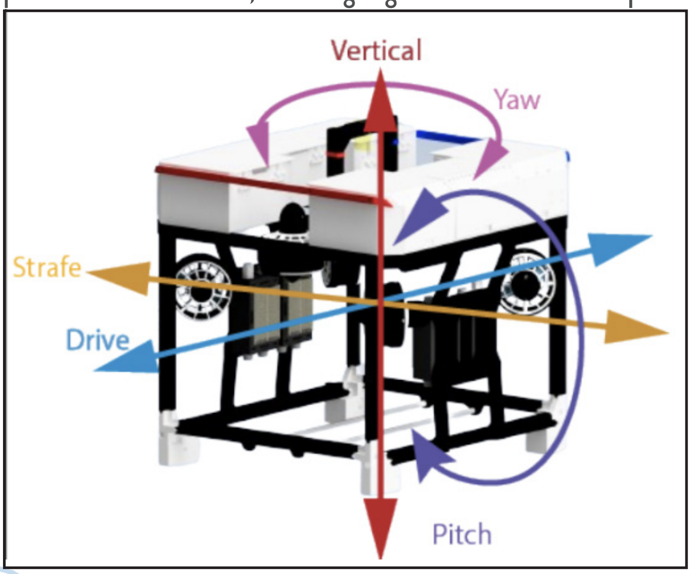

Figure 13. ROV degrees of freedom

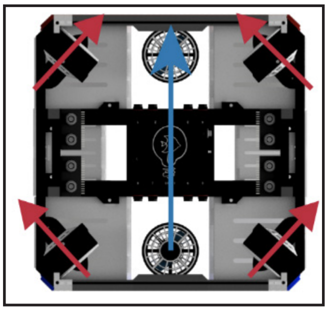

Figure 14. ROV drive

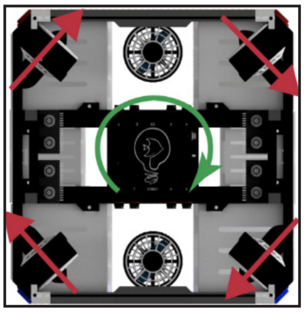

Figure 15. ROV rotation

Vehicle Structure

3D printing PLA+ was chosen for the majority of Amphitrite's structure alongside with 7mm aluminum hex rods that are integrated inside the rails that strengthens the ROV structure. The SMS5 rails are also integrated into the straight edges of our vehicle structure to allow compatibility with SMS5 while also maximizing space available for tool mounting and providing structural support. Cameras and tools can be placed at precise locations along the SMS rails according to the mission layout and pilot preferences.

The extensive use of 3D printing has enabled the layout and placement of the ROV tools, thrusters and other components to be designed ahead of the ROV structure. As 3D printing allows for geometrically complex structures to be manufactured with a relatively small increase in manufacturing difficulty with the structural parts of the ROV serving additional functions such as the aforementioned mounting for tools and cable management. Through the process of settling the layout and placements before designing the frame, the finalized design of the ROV structure has the onboard electronics hubs, cameras, thrusters and floats mounted at their most optimized positions, while freeing up the bottom of the ROV for tools and ballast. Safety principles have been incorporated into the frame's design, starting with the use with a safety factor of 2 in designing structural parts, where all parts of the frame can handle twice the amount of load as required during operation. Thrusters and electronics hubs are designed to be placed within the interior of the frame, reducing the chance of external contact with elements which may pose potential safety hazards. The adoption of integrating hollow aluminum hex rods within the 3D printed frame has allowed the

Figure 16. Amphitrite Structural Frame

frame to be much thinner, stronger and reduce hydrodynamic drag for faster acceleration. Individual parts of the Amphitrite frame are made to be modular, which allows parts to be easily upgraded and swapped out in case of damage, therefore improving the ease of maintenance of the ROV.

Standard Mounting System SMS5

The Standard Mounting System 5 (SMS5) is a patent-pending, fifth-generation 3D-printed quick mounting system developed by Fish Logic and serves as an attachment for tools and cameras on our ROV. SMS5 has a detachable clamp and a rail system which uses one M5 screw to attach and detach ROV tools and cameras onto the SMS rails. All payloads are SMS5 compatible just by incorporating the standardized centerpiece of the SMS5 clamp. Upon improving the previous design, SMS4, SMS5 has a center wedge component which increases durability and creates additional friction due to one extra contact surface.The SMS5 Clamp allows precise positioning of tools and cameras along the SMS rails on the ROV, providing precise locations for optimal tool placement.The SMS rail has been integrated with an aluminum hex rod which acts as a structural piece of the ROV frame. The SMS5 can resist movement up to 343N in the direction of the rail.

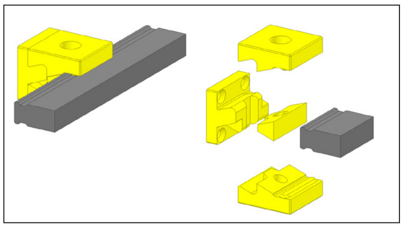

Figure 17. SMS5 (left) SMS5 exploded view (right)

The Micro Standard Mounting System 5 (mSMS5) was developed after the SMS5. It is a smaller, quick mounting system that is designed with the intention of carrying lighter loads such as cameras or cable clips. Similar to the SMS5, the mSMS5 clamp also incorporates the center wedge design which also creates additional friction. The smaller size allows our cameras to be mounted closer to the tools which provides better visibility for the pilot and consumes less space because of its size.

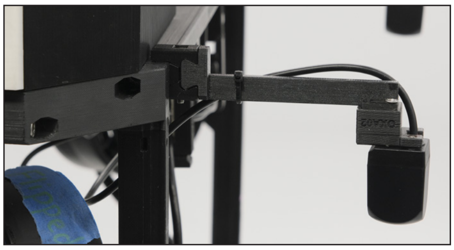

Figure 18. mSMS5 with Magnetic Camera Mount

Magnetic Camera Mount

The versatile design of the Magnetic Camera Mounts allows quick changes in the position and angle of the cameras without disassembly. The process of relocating cameras involves detaching and reattaching one magnetic mount to another with a slight pull, eliminating the need for tools. The time taken for this process has been reduced from 30 seconds to under 3 seconds, thus improving our poolside efficiency. Through the testing of cameras, members of Fish Logic manufactured the magnet enclosure to be a box-like shape with a running fit tolerance to help prevent camera vibrations and also ensure that the cameras only detach by a pulling force normal to the mount.

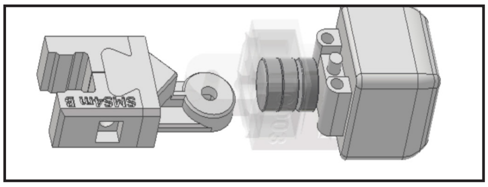

Figure 19. mSMS5 with Magnetic Camera Mount

Material

We chose the materials and manufacturing methods based on their ability to compliment each other's use case and the components' design. Therefore, 3D printing was chosen due to its design flexibility, ease of manufacturing, cost-effectiveness, and ease of designing and producing parts. PLA+ from eSUN is the choice of material for all the fused filament fabrication (FFF) 3D printed parts on Amphitrite. PLA+ is a blend of PLA with higher elongation at break, which makes it less likely to crack. PLA+ is a biodegradable thermoplastic that can be broken down by bacteria after use, which makes it environmentally friendly. For Amphitrite, aluminum rods are integrated into the frame to increase the structural strength and integrity, resulting in a thinner yet stiffer frame. Mask Stereolithography (MSLA) resin 3D printing is used to make small and precise parts because of its ability to print with a small layer height, for example, thruster guards and thruster electronic housing which provides better hydrodynamics. Moreover, it also provides a smooth outer surface and better hydrodynamics. Steel plates that are laser cut are attached to the tools and are the accessories to the electromagnets.

Materials	PLA	PLA+	SLA Resin	Aluminum	Steel
Density	1.24	1.24	1.18	2.7	7.84
Elongation at break(%)	5	29	6.2	3	15
UTS(MPa)	37	60	91	91	420
Use cases	Aesthetic prints such as the logo on the Control Box FlatPack due to higher dimensional accuracy	Main material used in most structural parts and tools of the ROV due to greater strength	Buoyancy Engine, Piston and Thruster ESC Housing due to complex prints needing high precision and prints being watertight	Aluminum laser cut 1mm plates for Gripper structural parts. Aluminum hex rods for strengthening ROV structure	Steel laser cut plates are attached to tools that interact with electromagnets

Table 1. Material choice

Buoyancy and Ballast

To guarantee the pilot's ease of use, Fish Logic aims for the ROV to maintain its depth and its upright position. To accomplish these aims, the average density of the ROV must be similar to the density of water;hence, neutral buoyancy. High density polyurethane (PU) foam is used to provide upforce to counteract the weight of the ROV in water by trapping less dense air in its structure. Foam chunks are cut into standardized sizes, which are fitted to the six float chambers on the top layer to provide a high center of buoyancy. To determine a more precise calculation of the volume of foam needed, our team uses an electronic scale to measure the weight of the ROV in water, and in finding the volume of the float to achieve neutral buoyancy after calculating the density of PU foam. The float chambers are designed to house more foam to offset the additional weight from the various payloads. Additionally, adjustments can be swiftly made as per opening the upwards-facing lids that allow easy access for the removal or addition of foam.

Four 25mm stainless balls are attached to the ballasts on the bottom corners of the ROV. This lowers the center of gravity while allowing the ROV to roll along the pool bed. The distance between the low center of gravity and the high center of buoyancy produces a restoring force (equilibrium), therefore enabling the tendency of staying upright in or above water.

The combination of the low center of gravity and the high center of buoyancy results in a much more stable ROV, suited for the pilot to maneuver and complete tasks smoothly.

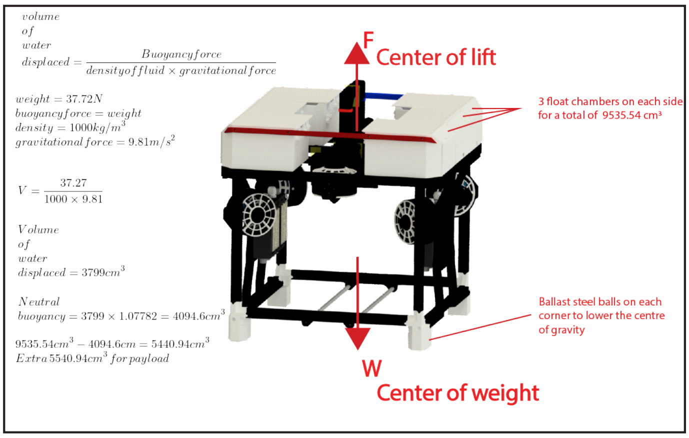

Figure 20. ROV Buoyancy calculations

Electrical System

SID

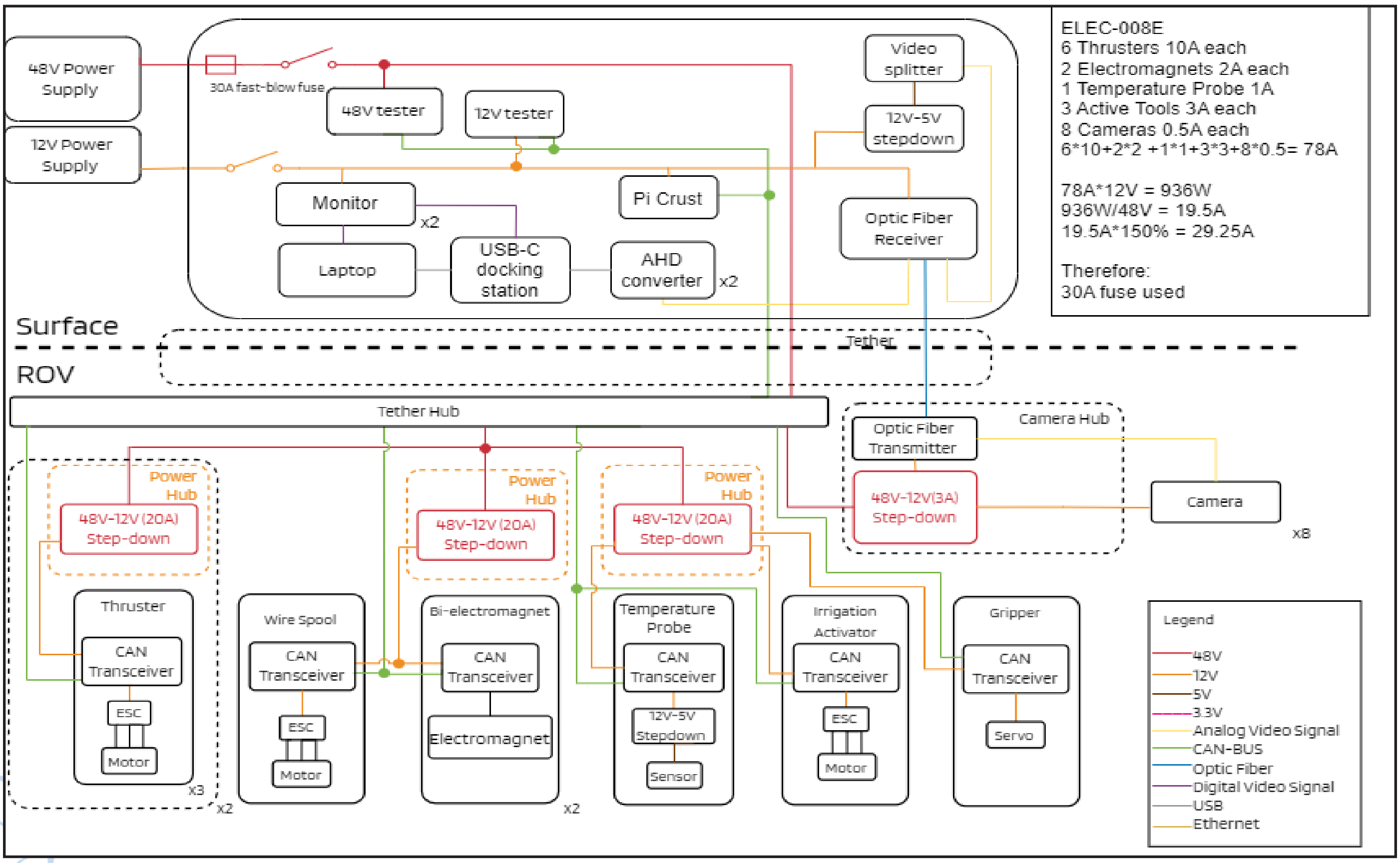

Figure 21. SID

Power Distribution

As Amphitrite operates at 48VDC, the tether supplies 48VDC into the tether hub. Since most of our devices on the ROV, for example: thrusters which operate at 12VDC, step downs are used in the power hubs to convert from 48VDC to 12VDC and to distribute power to the devices on our ROV.

The power tether uses a pair of 4mm² RVV cables rated for 22A. They are chosen as they contain a PVC Sheath layer outside which can enhance the mechanical strength of the wire and protect the cable from corrosion and mechanical damage. The signal tether uses a 0.15mm² TRVVPS cable which are shielded twisted pair cables. It is chosen due to its immunity to interference, the twisting helps with canceling external electromagnetic interference and reduces cross talk between neighboring pairs, the shield also reduces electrical noise from affecting the signal. The optic fiber cable is used as part of tether, due to its lightweight, flexibility and less susceptibility to noise, making it ideal to transmit camera signals, and contributes to the weight saving from (0.91kg) of 20m ethernet cable down to (0.28kg) .

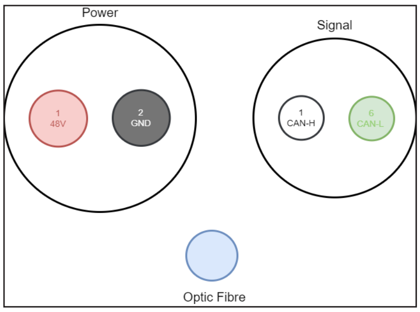

Figure 22. Tether cross-section

Our team has considered the use of a single neutral buoyant tether with a continuous foam sheath. However, the foam sheath is too rigid, as kinks on the tether would cause the ROV to rotate in water. A soft sheathed PVC cable (classified as RVV) is used for power delivery, and a soft shielded PVC (classified as TRVVPS) is used for signal tether.

Stress relief of the tether on the ROV is secured by a rope thimble that constricts the outer insulation of the power cable to prevent any mechanical forces applied to the cable from being transferred to the tether connector, potentially causing electrical terminations within the connector to break. To ensure no forces are transferred to signal and optic fiber cable, power tether is intentionally made shorter to provide slack for the signal and optic fiber cable.

There are 4 power hubs mounted on the sides of the ROV and each hub is capable of handling up to 20A in current, converting 48V to 12V to provide the required operational voltage to the devices. This reduces the current load of each power hub, and enables the power distribution system to be more modular and decentralized as there are less devices connected to each hub. To handle the maximum current draw of 18A needed to power up to 3 thrusters at the electronically limited max thrust, an off-the-shelf step-down converter rated at 20A was chosen. As each hub is attached to the ROV using 2 screws, a replacement can be swapped quickly in the unfortunate circumstance of a Power Hub failure.

Regarding the cameras, power is supplied through a camera hub which has a built-in 48VDC to 12V DC step down independent from the power hub modules used for thrusters and payload, this is done to prevent noise induced from the thruster from affecting the analog cameras.

Connectors

Amphitrite uses Weipu connectors due to their versatility in allowing different components to be easily connected in various sockets of the same type. These connectors combine signal and power into a single connector, allowing quick component swaps. The manipulators, such as the Bi-Electromagnet and thrusters, use 12V, 6-pin Weipu SP13 connectors, which can be directly connected to any power hub. For 48V components, 7-pin Weipu SP13 connectors are exclusively used to avoid any accidental mismatches with other connections. Each plug features two pairs of pins for power and ground; done to provide sufficient current for the manipulators since each pin is rated a maximum of 5A. Although the Weipu connectors claim to be waterproof, additionally, we apply epoxy and silicone grease between the pins and sockets in order to provide additional protection against potential water leakage.

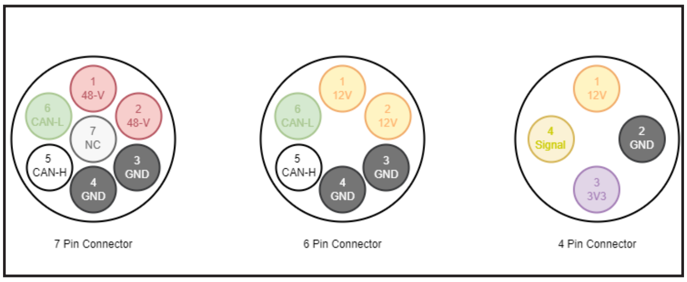

Figure 23. Connectors

Tether Management

The rules and protocols for tether management are reviewed by the tether managers in the operations team and abided by during the mission run.

Protocols for tether management is as follows:

1.	Never pull on the tether.
2.	Keep the workplace clean and organised for asafe and hazzard free environment.
3.	Tether is turned in the same direction to the ROV, minimizing the number of tether turns while operating to enhance maneuvering. Remove all kinks on tether before submersible recovery.
4.	Be observant of obstacles located near the submersible that have the potential to snag the vehicle or the tether.
5.	If the vehicle runs out of tether, there may not be enough slack to allow an easy turn around to follow the tether out. In this case, reverse vehicle direction to generate slack, and turn the vehicle around to manage the tether.
6.	When operating in an area containing obstructions or obstacles that could snag or foul the tether, the pilot should remember the route taken to get to any one position and the same route should be taken during extraction.
7.	If the tether does become entangled, do not pull the tether to free it.

Camera System

Amphitrite has a total of 8 cameras, 2 of which are mounted separately in the middle,facing front and the rear, for the purpose of navigation, as the ROV is capable of inverting directions. While the remaining 6 cameras act as secondary cameras which are mounted on the front SMS rails of the ROV to provide extra viewing angles for the missions specific tasks. The team had chosen Analog High Definition (AHD) cameras due to their 720p resolution instead of the regular 480p analog cameras, while still maintaining the low latency of analog cameras compared to their digital counterparts. The increase in resolution has provided extra clarity for the pilot vision as well as being able to distinguish further items during navigation. Since the cameras are IP68 rated waterproof vehicle reverse parking cameras, it only requires a preventive layer of UV resin to seal the outer shell seams. Each camera has a 4 pin connector for plugging into the signal and power.

The Camera Hub, placed at the center of the ROV top layer, digitizes all 8 channels of camera feeds and uses a transmitter to send a multiplex signal through an optic fiber tether to the surface. With the ability to transmit all 8 camera signals at the same time, it has removed the need for camera switching onboard the ROV, allowing the pilot and the team to have access to all camera angles simultaneously. The use of optic fiber transmission, along with a separate internal step down module for camera power has significantly reduced the noise impact from thrusters and the surrounding environment compared with using copper wires for signaling.

The optic fiber receiver converts multiplex camera signals from the ROV back to the 8 individual analog channels. The channels are put through 2 AHD capture cards that convert analog to digital video streams for the laptop. The Nvidia Encoder (NVENC) codec is used to decode camera signals. These signals are then sent to the 2 monitors through the USB-C Hub to provide the pilot with 4 different camera views on each monitor through Open Broadcasting Software(OBS). Additionally, a separate analog wire is splitted from the optic fiber receiver to a video splitter which provides MATE with live video footage from our ROV.


Figure 24. AHD Camera

Control System

CAN Bus System

CAN (Controller Area Network) is the messaging protocol used in the Amphitrite that allows onboard components to communicate with other components within the same bus network. Along with the Universal Connectors, the CAN bus is the key to achieving standardization for all of the electrical components of the ROV, as it allows any CAN bus device to connect to any sockets along the bus network. It also enables hot swapping, creates a flexible configuration, and modular and simplifies its circuitry and assembly, contributing to the ease of maintenance while simultaneously enabling future upgrades and expansion of the system.

CAN bus was originally designed for automobiles to reduce the amount of electrical wiring within. Due to its nature, CAN bus has features such as error checking and is less susceptible to noise, making it an ideal communication protocol for the length of tether used in the Amphitrite (30m). CAN bus was chosen over other alternatives mainly due to the durability and robustness of the network protocol. Compared to I2C, an alternative bus network used in previous Fish Logic ROVs, the Amphitrite CAN bus has experienced much less of the stability issues found in previous I2C implementations in Electro Stargazer, where errors increase as messages are sent more frequently leading to occasional program failures. The Amphitrite CAN bus network spans across the tether to the control box which runs the control program, allowing a direct connection to all nodes in the network without an onboard translator on the ROV that adds complexity into a central point of potential failure.

With no current implementation of CAN bus communication electronics small enough to be embedded onto the thruster, Fish Logic decided to carry out its own implementation in the form of a BeetleCAN, a custom CAN transceiver designed small enough to fit onto a thruster for each node in the network.

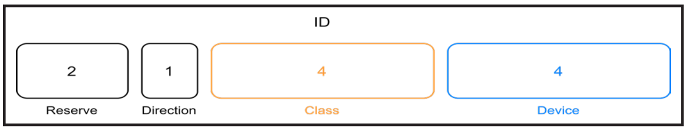

Figure 25. ID Structure

CAN Bus Software Protocol

The CAN bus network of our ROV is to be able to communicate with up to 20 nodes (connected devices). The 11-bit identifier of the messaging frame is used to specify the level of broadcast. The first level is the node level, where the messages are specific to one node. This requires each node to have a unique ID in order to receive required messages and ignore other messages by utilizing the mask and filter in the CAN transceiver. The class level allows messaging to all nodes in the same class, where nodes in the same class on the ROV are categorized by function. (e.g. thrusters, electromagnet and mechanical gripper) By having a global level that broadcasts messages to all nodes, it allows us to perform role calls to ensure that all nodes are responsive, as well as request for the onboard temperature and voltage readings from all nodes. Figure 24 shows a complete chart of ID to specify levels of broadcast amongst the various classes of each devices.The data comes after the ID, which takes up 1 to 8 bytes of the messaging frame. The first byte is reserved for the command function that the node should perform. This will be unique to every class, for example, 0x20 indicates the thruster spin command, with the second and third bytes reserved to indicate the speed and direction of the spin.

As messages are being broadcasted along the whole network, bus contention will occur when two or more CAN controllers start initializing messages at the same time as messages are being broadcast along the whole network. This could cause potential thruster movement delays or even stop transmitting messages completely. CAN bus resolves this issue by having every node that wants to transmit monitor the CAN bus. It then compares their IDs to see who has the more dominant bit (0) and the recessive bit (1), to which the dominant transmitter wins the arbitration. This action is repeated until 1 transmitter remains while the other potential transmitters wait until the CAN bus is free. To ensure smoothness in control, thrusters are prioritized, which results in the thruster IDs being set to have more dominant bits (0). Messages sent back from nodes, such as temperature and voltage data, should be of lesser priority than the ones being sent to the nodes.

Class	Thruster	Electromagnet	Motor
Global Level	0xFF	0xFF	0xFF
Class Level	0x1F	0x2F	0x3F
Node Level	0x11-0x1E	0x21-0x2E	0x31-0x3E

Figure 26. Thruster CAN Bus diagram

CAN Bus Thruster

The Amphitrite uses Blue Robotics T200 thrusters due to their powerful yet compact design. With the use of a CAN bus network, Fish Logic decided to integrate CAN bus electronics into the thrusters. The CJMCU Beetle is chosen as the microprocessor for its small profile, no larger than the width of 4cm. A built-in ATMEGA was chosen as it was a popular microcontroller featured in arduino. A printed circuit board (PCB) was also designed in-house to integrate a voltage regulator, CAN electronics, and voltage sensors into a similar size board that can be stacked onto the Beetle, small enough to fit within the enclosure. To maintain the streamlined and compact design of the thruster, the electronics housing is designed to match the same width of the thruster motor. The housing also utilizes the existing thruster screw mounts to avoid the need for any modifications to the rest of the thruster. Thus, MSLA (Masked Stereolithography) resin 3D printing is used to make the housing as it is able to print with thin layers, allowing us to obtain a smooth outer surface. MSLA also allows printing of thin perimeters (0.1mm) to maximize volume inside the housing for electronics. To communicate with the ESC (Electronic Speed Controller), CAN bus data is translated to Dshot protocol by the microprocessor. We chose Dshot as our protocol due to it being a digital protocol, meaning that it removes the need to do ESC calibration as opposed to analog protocols such as PWM (Pulse Width Modulation). Since PWM relies on the length of pulse to determine the value, the difference in speeds within the oscillator of the microcontroller and ESC may affect the value being sent. Being a digital protocol, Dshot is also less susceptible to electrical noise compared to analog protocols. All the software in the arduino is written in C++ which is responsible for performing command functions sent from the controller within the node.

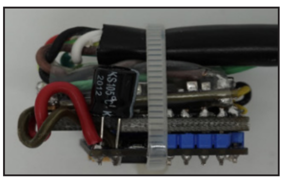
Figure 27. Thruster CAN Bus electronics

Control Program

The ROV control program consists of independent, loosely coupled modules, each serving a specific purpose. The whole program is written using Python. Python is a synchronous language by nature. However, many different processes and loops need to run together for the ROV to function. Therefore, the Python library Asyncio is used to help us schedule loops for execution. In the previous versions of the system, threading was used instead of async. However, program development with threads is more troublesome as problems were encountered with Python GIL (Global Interpreter Lock) and thread safety.

More importantly, GUI implementation using thread is very difficult. Thus, asynchronous programming was adopted for our system. Communication between modules is done by the library PyPubSub. Modules can broadcast messages while subscribing to specific topics.

ControlProfile.py	Changes the handling of the ROV by modifying max power and sensitivity
Thrusters.py	Ensures gradual acceleration of thrusters and compose data using thruster ID
CANHandler.py	Sends any data to the physical ROV system using the CAN protocol
PyGameServices.py	Instantiates all Pygame modules to be used, and calls pygame.event.pump() that internally process pygame event handlers
ModuleManager.py	Loads preset values from configuration file and manages starting and stopping of modules

Figure 28. Amphitrite Modules

PyGame, a library which is used for both Joystick and GUI modules, cannot work across multiple threads. The problem was later understood that the PyGame event handler had to be processed in the same thread as the PyGame display module was first initiated. A separate module named PyGameServices was used to instantiate all PyGame modules and processes all event handlers in the queue in the same thread. The initiated PyGame modules are then shared between the GUI and Joystick modules.

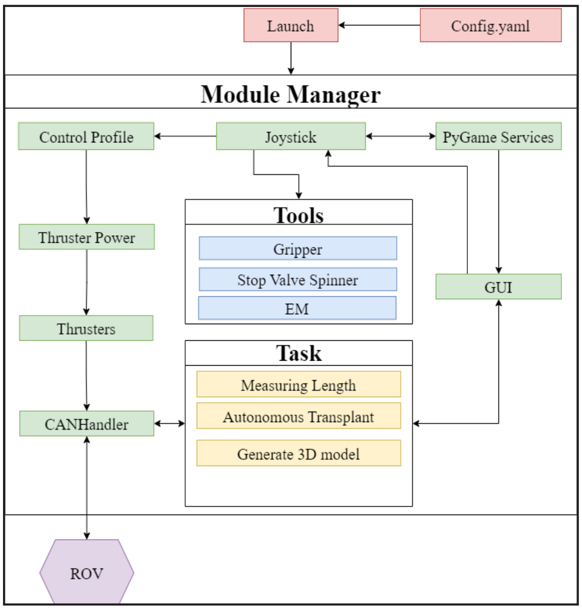

Figure 29. Amphitrite control program Modules

Thruster mapping

To convert pilot input into thrust values, the control software receives movement command inputs from the joystick module and processes the input values into a 6 dimensional vector with elements ranging from -1 to 1:

$$\mathbf{A_{IN}} = \begin{pmatrix} Drive \\ Strafe \\ Yaw \\ Vertical \\ Pitch \\ Roll \end{pmatrix}$$

The Moore-Penrose pseudoinverse is used in calculations to map ROV movement direction to the thrust power of each individual thruster. By measuring the position and direction relative to the ROV's center of mass, a matrix can be constructed that represents the contribution of each thruster to each DoF.

Key

$D - Drive$	$FL - Thruster\ Front\ Left$
$S - Strafe$	$FR - Thruster\ Front\ Right$
$Y - Yaw$	$BL - Thruster\ Back\ Left$
$V - Vertical$	$BR - Thruster\ Back\ Right$
$P - Pitch$	$UF - Thruster\ Up\ Front$
$R - Roll$	$UB - Thruster\ Up\ Back$

$$\begin{pmatrix} A_{IN} = BX_{OUT} \\ B^{\dagger}BX_{OUT} = B^{\dagger}A_{IN} \\ X_{OUT} = B^{\dagger}A_{IN} \end{pmatrix}$$

The combined thrust to reach the desired effect of B can be calculated as follows:

Where $B^{\dagger}$ *is the Moore – Penrose pseudoinverse of matrix B*
X_{IN} *is the 6x6 matrix mapping thruster contribution and DoF*
A is a 6 dimensional vector containing the movement command
X_{OUT} *is the resultant 6 dimensional vector containing required power of each thruster*

$$\mathbf{X_{OUT}} = \begin{pmatrix} FL \\ FR \\ BL \\ BR \\ UF \\ UB \end{pmatrix}$$

Calculation with matrices and vectors is chosen as opposed to hard coding the calculations for each thruster's power individually. It allows the code to be more concise and can easily adapt to changes in the thruster configuration by editing the preset matrix. This algorithm can factor in the imbalance of force or asymmetrical placement of thrusters to provide more accurate movements thus any command from the pilot will result in the desired movement of the ROV.

GUI

The Graphical User Interface (GUI) is designed to aid the pilot in the operation of the ROV, and help the team with troubleshooting the control program and ROV systems.

The GUI elements are designed and placed strategically to be viewable at a glance. Clear indicators are displayed for each control of the ROV, whether it is done with printed text or a graphical indicator.

Status bars are used to display the thrust values of each thruster. Gripper movement prompts that indicate the static, opening or closing states are displayed to help diagnose issues with the input interface or Control Program.

The GUI utilizes the PyGame Library in order to draw the graphical elements. PyGame is chosen for its ease of use and highly modular architecture, with only GUI and Joystick modules utilized to minimize performance impact. The GUI communicates with other modules with PyPubSub and subscribes to all the data that needs to be displayed.

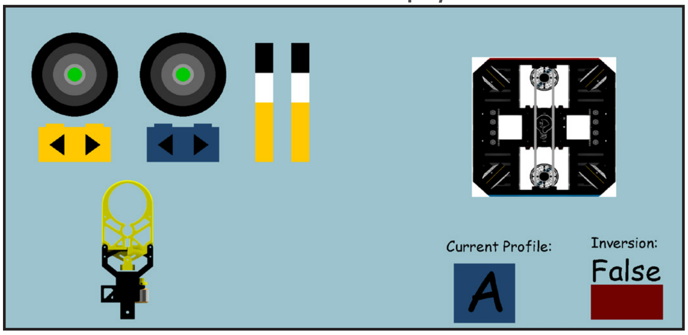

Figure 30. GUI

Control Box

The Amphitrite Control box contains two 24 inch 75Hz 1440p monitors that allows the pilot to see all 8 cameras in their native resolutions. Below the monitors is the control box, which serves as the central hub for all the connections to the ROV and back. The control box houses a PI Crust which contains a raspberry pi 4 that runs our control program, an optic fiber receiver, 2 AHD hubs, a thunderbolt 3 hub and a AHD to HDMI video converter. The control box is the primary conduit of power to the ROV with 48V and has a built in kill switch that allows for complete cut off of power incase of an emergency. Moreover, the control box is supplied with 12VDC which powers all the electronic components within the control box. The control box also transmits and receives control signals to and from the ROV's devices. It also plays a crucial role in providing camera visuals to the pilot as it receives camera signals through an optic fiber from the ROV, which are then relayed to the laptop though the camera system. Notably, the control box does not require the use of AC power.


Figure 31. Control box


Figure 32. Control box electronics

Mission Specifics

Bi-Electromagnet

The Bi-Electromagnet (BEM) is a general-purpose tool used to release the recovery float, connect the recovery line, install the power connector, deploy the Acoustic Doppler Current Profiler (ADCP) and gather sediment samples. The choice to use electromagnets was due to their simple working principle with no moving parts, making them easy to manufacture, maintain, and use while being reliable and versatile for many tasks. Each BEM consists of two individual electromagnets positioned next to each other. Amphitrite, equipped with two BEMs, has four total electromagnets that can be individually turned on and off, thus giving it the maximum capacity to hold four objects simultaneously. The center point between the two electromagnets has space between them to allow for two attachments on a single BEM. The two electromagnets on the BEM have a combined force of attraction of 36 kg. LEDs are embedded into the BEM to indicate the on and off status of the individual EMs. The polarities of the electromagnet can be reversed to counter magnetic hysteresis, where light ferrous objects that are magnetized remain attracted to the BEM even when the electromagnet is switched off using an onboard H-bridge motor driver. The BEM is mounted to the ROV bottom corners using the BEM Adapter. The adapter has multiple mounting holes above the BEM to allow attachments such as the Double One Way Latch or the Sediment Passive Claw to function as BEM attachment tools.

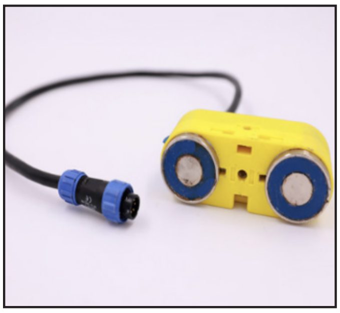

Figure 33. BEM

Figure 34. Photo of the BEM with the adapter and Sediment Sample Claw attachment

Task 1

Recovery Line

The Recovery Line connects to the bale on the multi-function node to allow its retrieval. It is attached to the BEM using a steel metal plate mounted behind the U-shaped trap with 2 attracting flaps opposite of each other that securely latch onto the U-Bolt of the bale. A rope tied onto the Recovery Line is tethered to the shore. The BEM is deactivated, the Recovery Line is released from the ROV once the connection is secured. Our team decided to build our own Recovery Line due to previous challenges we encountered with carabiners. We observed that since the carabiners were attached to the prop using zip ties, they tended to slide along the PVC pipe, which made it challenging for the pilot to push the carabiner down onto the U-Bolt.

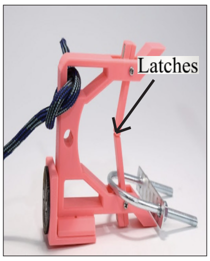

Figure 35. Recovery Line

Task 2

Smart Repeater Holder

During Fish Logic's water test, our team discovered that when installing the power connector, the metal hook on the Subsea-SMART repeater made it top-heavy. This means that the Subsea-SMART repeater could easily topple over, making it difficult for the pilot to install the power connector. We developed the SMART Repeater Holder to transport and anchor the subsea-SMART Repeater upright using the BEM to prevent this. It consists of a cage with a hinge in one corner to hold the SMART Repeater while steel plates are placed in the other end for the BEM to hold on to, keeping the cage closed during transport. Once the Subsea-SMART repeater is deployed, two 50g brass weights are mounted on the top to ensure the cage remains temporarily closed until the ROV removes the holder from the Subsea-SMART repeater. After the power connector is installed, the holder is removed when the BEM latches onto the top steel plate with a lifting motion of the ROV causing the hinge to swing open due to gravity to release the Smart Repeater.

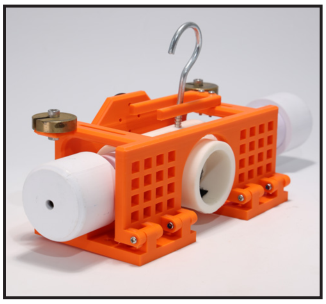

Figure 36. Holder

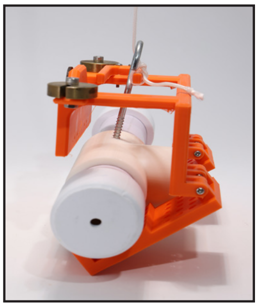

Figure 37. Holder Released

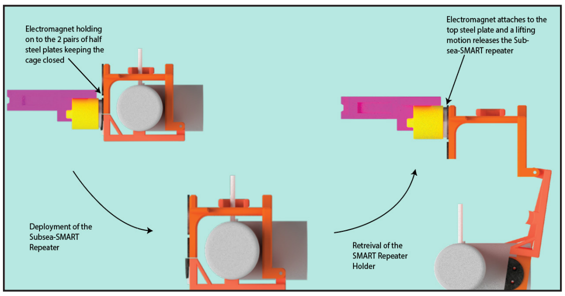

Figure 38. SMART Repeater diagram

Power Connector Retriever

The Power Connector Retriever is a BEM attachment that functions as a carabiner. It enables the ROV to retrieve and insert the power connector to the subsea SMART repeater. The attracting one-way latches on the hinge latch onto the power connector. The distance between the latch and the opposite side was customized according to the measurements of the 1-inch PVC's outer radius with tolerance to ensure the pilot's ease of use of the tool since the prop is fixed in place when the pilot is installing the power connector. The pilot does the following to retrieve the power connector: First, activate the BEM, it attracts the metal plate on the latch, this action causes the mechanism to swivel onto a hinge connected to the BEM, thereby locking the latches. The ROV will then be positioned above the power connector before descending to latch onto the 1-inch PVC and successfully retrieving

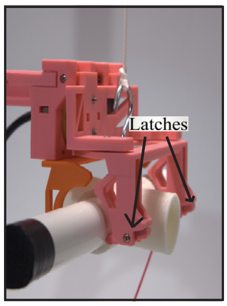

Figure 39. Power Connector Retriever

the power connector. The pilot turns off the EM which unlocks the latches and releases the power connector once the power connector has been inserted into the SMART repeater.

Temperature sensor

To measure the temperature of the SMART Repeater temperature probe, the team developed a new temperature sensor to mount onto the bottom rail of our ROV. We chose the Maxim DS18B20 temperature sensor for its accuracy, reliability, wide measurable temperature ranging from -55 °C to 125 °C, and its built-in waterproofing capabilities. The readings are retrieved from the DS18B20 sensor by one of our CAN beetle microcontrollers and sent back to the Raspberry Pi through the CAN Bus network.

Figure 40. Temperature sensor

Task 3

Stop Valve Spinner

In order to successfully activate the irrigation system, the ROV is equipped with the stop valve spinner. The stop valve spinner is mounted on the corner side rail which allows for convenient piloting. The spinner meshes with the valve handle along its internal grooves. When the brushless motor is activated, the valve handle will spin 360° clockwise.

To spin the valve handle, a 0.5 module 12-tooth driver gear drives an 84-tooth gear to create rotational motion with a 1:7 gear ratio. This creates enough torque to spin the valve handle and activate the irrigation system.

A brushless motor is chosen as it allows for continuous rotation of the stop valve spinner. In addition, due to its reliability and modularity, the stop valve spinner can be easily adapted to our present system.

Figure 41. Stop Valve Spinner

Autonomous Program

The ROV is mounted with the stop valve spinner to activate The autonomous program is used to facilitate the transportation of the brain coral from the nursery to the restoration site. Utilizing OpenCV, the system scans for a 15 cm x 15 cm square of red Velcro using the top rail camera.

To complete the restoration, the pilot retrieves the brain coral and activates the autonomous program. Upon activation, the ROV moves autonomously while continuously attempting to detect red Velcro. Once a part of the red Velcro is identified, the ROV will align itself to the optimal position and descend. When the operation is completed, the pilot releases the brain coral on the restoration site.

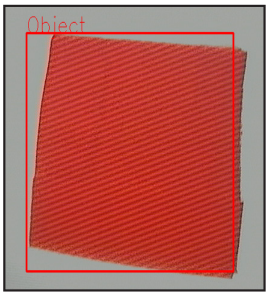

Figure 42. Detection of Red Velcro with OpenCV

Measuring Program

To measure the dimensions of the coral restoration area, a measuring program written in Python serves the purpose.

Since we know the dimensions of the top corrugated plastic sheeting, we can use that as a reference for the dimensions of the whole coral restoration area. Using Opencv, the user first draws a line with known dimensions and then calls it a reference line. Then, the program prompts the user to input the length in cm. Next, the user draws a second line representing the length intended to be measured. The pixel length of the lines could then be calculated using the Euclidean distance formula. Afterwards, the calculated pixel lengths of the 2 lines and the referenced length in cm are used to calculate the actual length of the second line.

$$D = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Euclidean distance formula

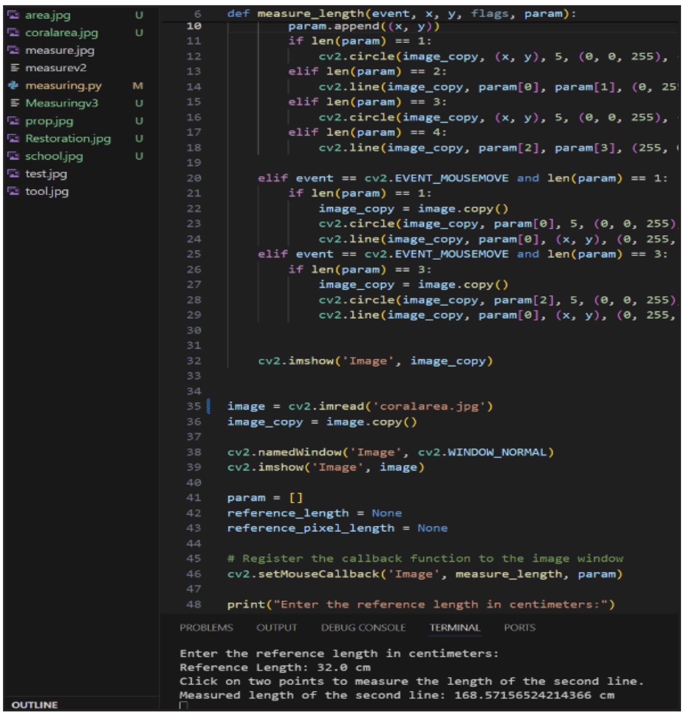

Figure 43. Measuring Program output

Figure 44. First line drawn as reference measurement

Figure 45. Second line drawn to measure coral restoration area's length

ADCP Clasp

The ADCP latch is a 3D-printed attachment to the BEM for the deployment of the ADCP. When the BEM is activated, the flap will be attracted to the EM as the flap has a metal plate, hence holding onto the ADCP by providing a firm grip around the 2-inch PVC. When the EM is deactivated, the flap will swing open and deploy the ADCP at the designated location.


Figure 46. ADCP Clasp

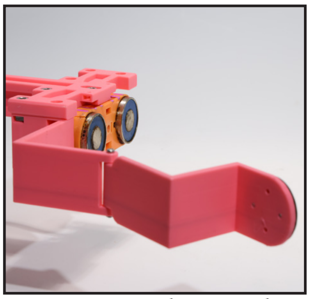
Figure 47. ADCP Clasp opened

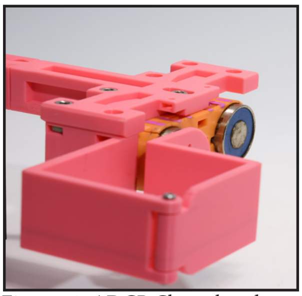
Figure 48. ADCP Clasp closed

Sediment Sampler Claw

The Sediment Sampler Claw is an attachment to the BEM used to collect and transport Mexican pebbles. When the BEM is turned on, the steel plate mounted on the top claw is attracted to the BEM, holding the top claw open. When the BEM is turned off, a 76-mm-long torsion spring forces the top claw to close, which retrieves the Mexican pebble rocks.

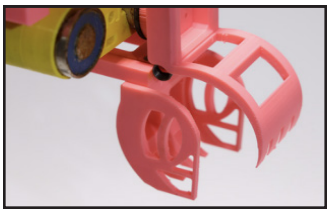
Figure 49. Sediment Sampler Claw (Opened)

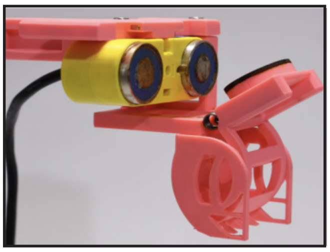
Figure 50. Sediment Sampler Claw (Closed)

Task 4

Haku Profiling Float

Haku is the third vertical profiling float designed by Fish Logic, and is an evolution of Fish Logic's previous two GO-BGC floats: Ponyo (2023) and the SeaLift (2022). Ponyo utilized a buoyancy engine with a peristalsis pump to transport water between the pool and an internal bladder. However, when the pump malfunctioned, the internal bladder burst. Therefore, Fish Logic had decided to take a different approach in order to make it failsafe.

Haku is designed to complete two vertical profiles within fifteen minutes. The mechanism of the buoyancy engine in Haku consists of a piston that draws and pushes water to the external pool. To maximize changes in internal volume, the piston with 2 O-rings spans across the whole inner diameter of the canister. This allows the largest diameter piston to fit within the canister. Since any small movement caused by the piston can have a significant large change in volume, the piston is actuated by a power screw where a DC Motor drives a threaded rod. Afterwards, a threaded block turns the rotational motion into linear motion. Limiting switches are placed at both ends of the mechanism to determine the maximum and minimum travel.

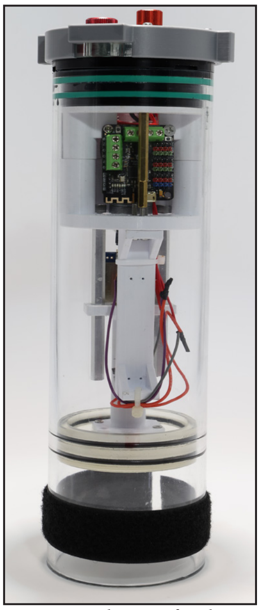
Figure 51. Photo Of Haku Vertical Profiling Float

The piston is 3D printed in SLA resin to guarantee its waterproofness. SLA printing also has the precision to ensure the watertight seal between the 2 O-rings of the piston and the canister wall.

Not only do piston groove dimensions need to be ensured to allow for an effective watertight seal, but the O-ring seal must also not be too tight, lest its friction overcome the driving force of the motor.

When the float reaches the surface, a float-attached magnet in a tube outside the canister descends to activate a hall effect sensor within the housing to indicate that the surface has been reached.

Haku is transported to the designated area by the ROV using the Gripper before being deployed. The mission station will then send a command to the Arduino to initiate a vertical profile.

Weights are attached at the bottom and adjustable floats are mounted at the top of Haku to ensure its stability when profiling and allows for the fine-tuning of buoyancy.

Haku utilizes a 300mm tall watertight enclosure. All electrical components are powered by 8 AA alkaline, non-rechargeable batteries, which are ideal for fitting into the confined space of the canister. The batteries are connected in series to generate a 12V output voltage. The motor is managed by an integrated motor driver within the Romeo BLE mini V2 Arduino. The Arduino, connected with an antenna, enables Haku to communicate with the mission center using radio waves. Haku features wireless communication capabilities which allows for reprogramming, manual control, and transmission of information to the mission station immediately upon resurfacing.

To gather depth data, Haku uses the Bar30 High-Resolution 300m Depth Sensor from Blue Robotics. The depth data gathered across the vertical profile, along with the corresponding UTC time stamp, will be transmitted to the laptop at the mission station upon the float resurfacing. Subsequently, the mission station could track the float's depth changes over time on a graph.

In a scenario where the internal pressure of the canister exceeds the pressure outside, a pressure release valve with a sealing diameter of 2.5cm will pop out of the canister.

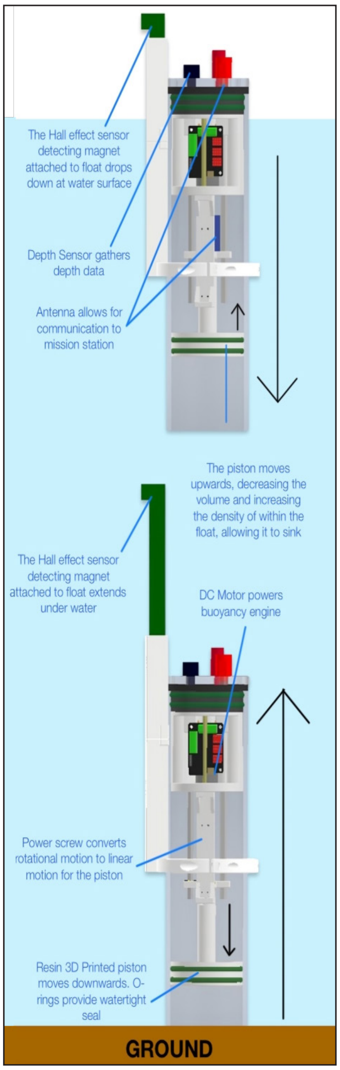

Figure 52. Motion of Haku at water suface and pool bed

Mission program

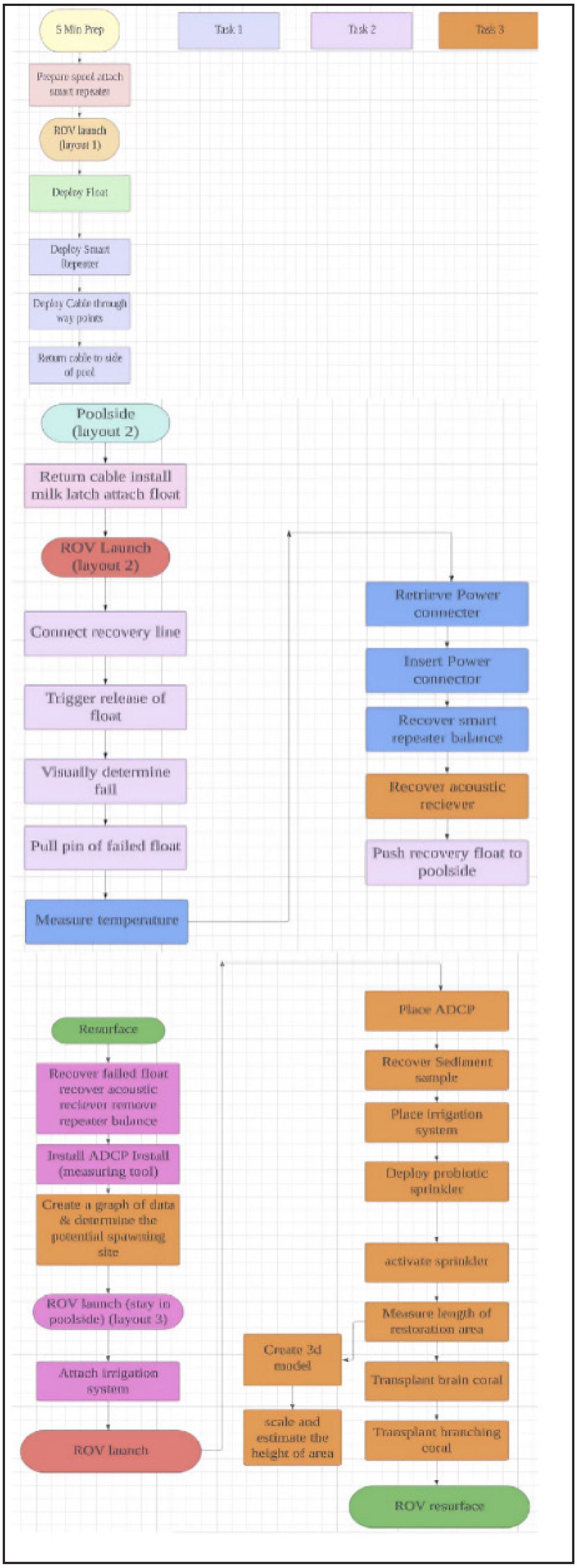

Figure 53. Amphitrite Mission Program

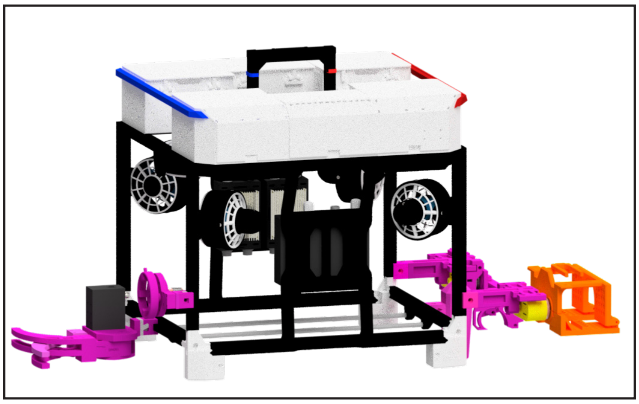

Figure 54. Amphitrite Layout 1

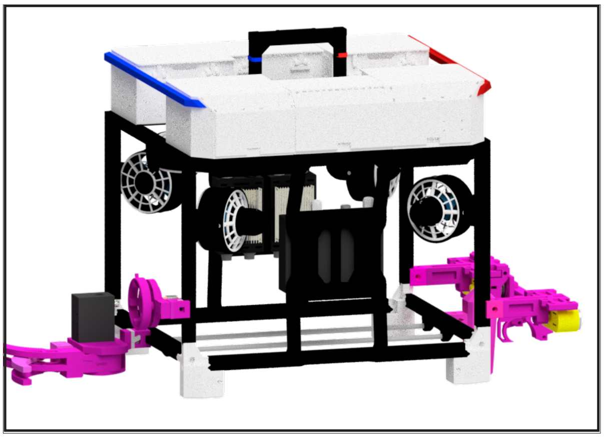

Figure 55. Amphitrite Layout 2

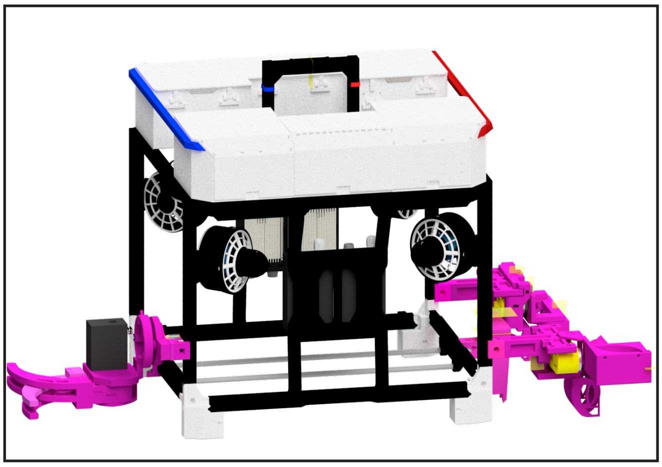

Figure 56. Amphitrite Layout 3

Fish Logic uses the mission program to define the layout of the ROV. The complete mission program is the final verification that all mission tasks can be completed within the time limit of the product demonstration. The order of the mission program is set based on task difficulty, tool combination and distance between tasks to ensure a streamlined sequence of tasks for the pilot to execute. The tool combination between each return to the surface is grouped as a layout that our operation team can reliably set up. Systems engineering is used to ensure that all the tools are well integrated with each other without compromising their individual functions. The final mission program requires 1 resurfacing and 2 poolside tool changes, thus we have created 3 layouts which allows all tasks to be completed within the 15 minute time limit.

In-house built Vs. Commercial Components

Fish Logic fabricates in-house components to achieve innovation and unique functionality that is not commercially available. The components are evaluated based on these aspects: their performance, reliability and the feasibility of our members, with the components which exceed the team's fabrication capabilities, such as cameras, monitors and the gamepad are purchased commercially.

Fish Logic aims to improve numerous components, and to do so, we first search for commercially available parts. Then, the parts that fulfill the required specification are compared to the resources and required skills to fabricate them in-house. Each part's features, performance, cost and especially reliability are researched extensively before purchase. Fish Logic will only consider whether the team has the time, resources and skills needed to fabricate them when no suitable parts are commercially available

Regarding thrusters, we have chosen the commercial T200 thrusters due to their outstanding performance. However, as there are no commercially available CAN bus transceiver modules small enough to fit within the ESC housing of the thruster, a custom PCB was designed and sent to a manufacturer to be printed. This resulted in a custom CAN bus transceiver that is compatible with an arduino microcontroller and small enough to fit within the ESC housing to be waterproofed.

New or Reused Components

Fish Logic strives to continuously innovate and improve all aspects of the ROV. The decision on whether parts are reused depends on the new features needed, possible improvement in performance, effort needed to fabricate and financial cost of the components itself. Amphitrite is a small evolution of last year's ROV, Siren. This led to Fish Logic's decision to reuse the core electronics that were in common with Siren because Amphitrite's base platform only had minor changes from the previous Siren. This maintains the commonality between platforms and has the added benefit of using Siren as our stable testing platform.

As last year's control box and monitor stand was lacking in terms of reliability and convenience, we have decided to redesign a new control box, that can fulfill all our use requirements while allowing us to repurpose the aluminum extrusions and Siren's' box. This decision enabled us to achieve cost-saving measures and reduce the time needed to source materials.

Testing and Troubleshooting

Vehicle Testing

In regards to testing, Fish Logic's testing principles are to design a testable system and then test the system in a way that simulates how it will work in reality. Rapid design-build-test cycles that maintain a continuous design heritage are to inform the next design by the experience gained.

Documentation and testing processes become more formal as the system matures. Tests are categorized into development, qualification, and acceptance tests. Development tests are used to determine the hardware's capabilities when it exceeds the requirements of the competition with the aim to find weaknesses, such as the 20-meter water pressure test, ultimate strength tests, etc. This tests their reliability in different scenarios and gathers important data like: video footage, forces and power draw, etc. Qualification tests demonstrate hardware performance limits, where components are tested with the worst-case conditions plus the required safety factor. This helps to understand the characteristics of the tools when functioning near the designed limits. Acceptance Tests verify workmanship and functionality, ensuring the design is of a suitable quality. All components are acceptance tested before being certified for use on the ROV. Hardware in the Loop (HITL) verifies hardware-software integration. For every hardware-software change, a full system test is performed as the acceptance test.

Prototyping and Testing

The development of Haku was the best example of the rapid design-build-test cycle used by Fish Logic. Haku had to be designed to complete two vertical profiles within fifteen minutes. Due to the weak structure and instability of the previous Ponyo, a new design which was failsafe was being researched. A conceptual prototype of Haku was first built using readily available materials. The design consisted of a moving piston across a 90mm diameter canister, allowing Haku to become a syringe. Prototype electronics consisting of AA battery holders, a DC motor, limiting switches and an Romeo BLE Mini v2 Arduino were put together. The Romeo BLE Mini v2 Arduino controlled the moving piston via a power screw mechanism, allowing for a volume change of 1100mL within Haku.

Each sub-system went through a qualification test before assembly. The electrical system was tested with a multimeter after everything was soldered. Water seal tests were conducted to ensure that Haku was waterproof up to 5 meters. The power screw mechanism was tested with a bench power supply. After qualification of every sub-system, the whole vertical float was fully assembled and tested in a large tube filled with water. Subsequently, the prototype underwent further testing in an inflatable pool.

During the test, the excessive friction on the O-Rings of the piston posed a risk of displacing the electronics from the canister, rather than allowing the piston to smoothly move within the canister. To address this issue, Fish Logic decided to modify the piston's groove diameter as well as the O-Ring thickness to reduce friction. The piston was manufactured using 3D printing in SLA and due to its cost, Fish Logic was limited to creating only two pistons with varying groove diameters. Therefore, O-Rings of different diameters and thickness were mounted on the piston and trialed systematically. The piston would be activated with different O-Rings mounted and the time taken for the piston to complete a full vertical profile with each type of O-Rings will be evaluated individually. The type of O-Ring used was selected based on its ability to record the fastest time to complete a vertical profile while maintaining watertightness. In addition, silicone grease was applied to the edges of the piston to reduce friction and act as a failsafe.

A second iteration of Haku was designed. An antenna to communicate with the mission station, a depth sensor to gather depth data, and a modified piston was added. The qualification tests were repeated, this time including a full on-land run of Haku to ensure the friction problem did not persist. This iteration was tested in an inflatable pool, then in a 2m deep Olympic standard swimming pool. Haku was able to achieve a sinking and floating speed of 0.05 m/s, complete two vertical profiles, and send data back to the mission station within 5 minutes, leading us to the conclusion that all the systems work as intended.

Building 2 prototypes in rapid design-build-test cycles has allowed Fish Logic to discover and solve problems sooner, rather than fixating on meticulously planning and executing initial design solution, which may have not met our performance requirements.

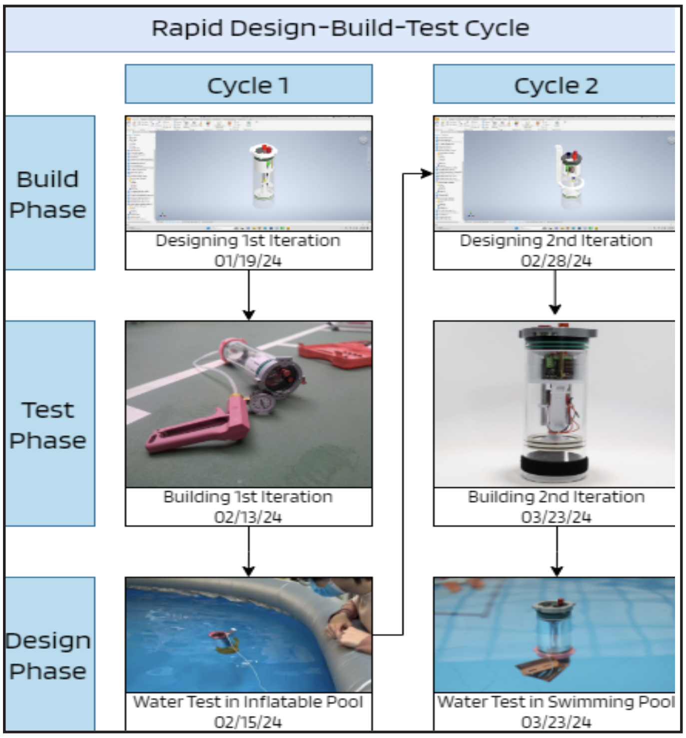

Figure 57. Haku Rapid Design-Build-Test Cycle

Troubleshooting Strategy

When selecting the propulsion system for Amphitrite, our team decided to replace the Blue Robotics T100 thrusters from last year's Siren with more efficient T200 thrusters. However, this change led to the ROV rotating unexpectedly while driving and strafing at a lower profile, this issue remained unresolved even after changing to a higher profile.

Initially, we suspected the issue stemmed from the control program, as we had originally ran our control program on a laptop. The choice of running the control program on a laptop and using a Raspberry Pi 4 only as a CAN bus transceiver is to take advantage of the laptop's performance in order to attempt AI and photogrammetry tasks.

Despite thoroughly checking the program and fixing the GUI display, the ROV continued to rotate. After resurfacing the ROV, we noticed that the front left thruster was vibrating instead of moving. We tested the thruster independently by directly sending commands to it and it spun properly, eliminating the possibility of it being a mechanical issue.

Then, we tried verifying if it was a CAN bus signal rebound issue since we were unsure if it was a termination resistor problem. However, even after the verification, the issue persisted. Eventually, we replaced the new T200 Thrusters with the old T100 Thrusters that were proven to be reliable and the issue did not resurface. This led our team to conclude that the problem had originated from the use of T200 thrusters.

After further research on the Blue Robotics forum, we found a suggestion to turn off the "low RPM power protect" and "demag compensation" options on our ESC settings to fix the issue. These settings were originally for quadcopter to protect their brushless motors. The T200 thrusters we used are much lower KV compared to drone motors, thus their operating RPM are low enough to trigger low RPM protection of the ESC which prevents the thrusters from moving. As our BlHeli HAKRC AT421 ESCs includes these features, we now strongly believe that this was the solution to our problem.To confirm our theory, we reprogrammed our ESC and set up a test rig for our T200 Thruster without "low RPM power protect" and "demag compensation" enabled. We tested out the Thruster with the rest of the system and the issue was no longer present.

Our team learned from this experience that a systematic troubleshooting approach, thorough review of documentation and diligent research are essential for effective problem-solving. Utilizing these methods would have prevented wasted time on ineffective experiments.

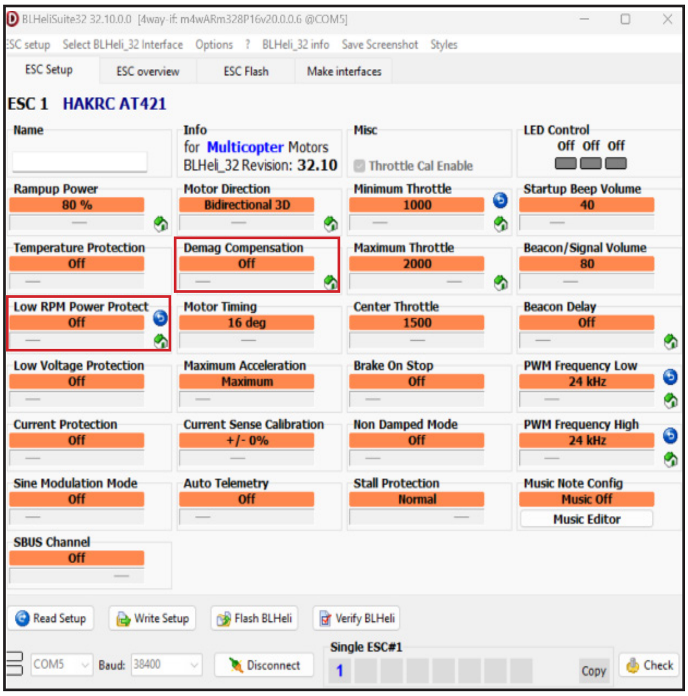

Figure 58. ESC Settings

Finance

To balance our finances, Fish Logic requested that our mentor to apply for funding based on our planned budget from our school, Macau Anglican College (MAC). MAC has provided Fish Logic with generous funding for our current project, Amphitrite, as well as our previous endeavors. On top of that, Fish Logic has fundraised by selling merchandise during school events as a secondary source of funding.

School Name:		Macau Anglican College				From:	01/09/2023
Instructor:		Ryan Chan		Reporting Period:		To:	22/06/2024
Team Name:		Fish Logic					
Date:	Type:	Catagory:	Description:	Unit Price:	Quantity:	Expenses:	Running Balance:
01/09/2023	Cash Donated	Funds	Funds from Macau Anglican College	$3,600.00	-	-$3,600.00	$3,600.00
01/09/2023	Fundraising	Funds	Funds from selling merchandise	$286.00	-	-$286.00	$3,886.00
01/09/2023	Re-used	Electronics	720p AHD Camera	$11.44	8	$91.54	$3,886.00
01/09/2023	Re-used	Electronics	Tether	$156.00	1	$156.00	$3,886.00
01/09/2023	Re-used	Electronics	CAN Transceiver (Beetle CJMCU)	$4.29	12	$51.50	$3,886.00
01/09/2023	Re-used	Electronics	CAN Transceiver (Beetle CAN PCB)	$0.48	12	$5.73	$3,886.00
01/09/2023	Re-used	Electronics	Optic Fibre	$8.58	1	$8.58	$3,886.00
01/09/2023	Re-used	Electronics	Motor Driver	$0.72	2	$1.43	$3,886.00
01/09/2023	Re-used	Electronics	Stepdown Converter(48V to 12V)	$23.60	5	$117.99	$3,886.00
01/09/2023	Re-used	Electronics	ESC	$12.16	8	$97.26	$3,886.00
01/09/2023	Re-used	Electronics	Raspberry Pi 4	$130.00	1	$130.00	$3,886.00
01/09/2023	Re-used	Hardware	Blue Robotics Thrusters	$136.31	6	$817.85	$3,886.00
01/09/2023	Purchased	Hardware	Power Supply	$123.50	1	$123.50	$3,762.50
01/09/2023	Re-used	Hardware	Gamepad (X-box Controller)	$104.00	1	$104.00	$3,762.50
01/09/2023	Purchased	Hardware	Optic Fibre Receiver and Transmitter	$57.21	2	$57.21	$3,705.29
01/09/2023	Purchased	Hardware	AHD Capture card	$100.11	2	$200.23	$3,505.06
01/09/2023	Re-used	Hardware	Electromagnets	$4.29	4	$17.17	$3,505.06
01/09/2023	Purchased	Electronics	Laptop	$1,766.96	1	$1,766.96	$1,738.10
01/09/2023	Purchased	Hardware	Esun PLA+ Filaments	$12.87	30	$386.18	$1,351.92
05/11/2023	Purchased	Electronics	24 inch Monitors	$42.76	2	$85.53	$1,266.39
10/11/2023	Purchased	Hardware	ESC	$9.21	10	$92.14	$1,174.25
05/12/2023	Purchased	Electronics	Control Box Cables	$2.87	20	$57.49	$1,116.76
10/02/2024	Purchased	Hardware	D Hook	$1.15	10	$11.45	$1,105.31
13/02/2024	Purchased	Hardware	Gear Pump	$5.72	1	$5.72	$1,099.59
13/02/2024	Purchased	Electronics	BGC Electronics	$21.45	1 set	$21.45	$1,078.14
29/02/2024	Purchased	Electronics	Thunderbolt 3 dock	$91.00	1	$91.00	$987.14
25/03/2024	Purchased	Travel	Transportation to Hong Kong	$338.00	1	$338.00	$649.14
25/03/2024	Purchased	Travel	To Swimming Pool	$189.32	-	$189.32	$459.82
13/05/2024	Purchased	Hardware	PU foam	$7.93	2	$15.86	$443.96
13/05/2024	Purchased	Electronics	ROV maker brushless motor	$21.19	3	$63.57	$380.39
Total Raised:							$3,886.00
Total Spent							$3,505.61
Final Balance							$380.39

Figure 59. Finance table

Budget Planning

As the project commences at the end of the previous competition, a budget is prepared by the team with estimated expenses based on the previous ROV's expenses. The income is estimated approximately to the funding and is included into the budget plan. Once the income has been received, the team verifies that the amount meets our income to see if adjustments to the budget needs to be made. The team must stick to the budgeted expenditures by reviewing the budget at the end of each sprint cycle. Additionally, purchasing costs are allocated for development of tools based on the budget for the next sprint cycle. Whenever receipts are collected, it is entered into the budget. A project costing sheet is compared against the budget to make sure that the capital is used properly and no capital is wasted.

For transportation costs to the local pool, Fish Logic evaluated different trucking services and chose them based on the criteria of cost, service, reputation, and punctuality. Once the truck service was selected, the budget was allocated based on shipping costs and the number of pool access dates. With our school sponsoring our shipping costs, travel costs planned for the regional competition (Tsing Yi, Hong Kong) were significantly reduced.

To incorporate finance planning in Scrum project management, Fish Logic created a budget estimation based on the tasks of each sprint and the release planning at the beginning of the year. At the beginning of each sprint, the CFO allocates the budget set for the current sprint for the team, with each spending recorded in an Excel spreadsheet. At the end of each sprint, the team re-analyzes the efficiency on budget spending and leftover budgets would be reallocated to other sprints.

With Fish Logic's focus on maximizing in-house built parts, the cost of production could be controlled. An example would be the Gripper V4. During the development of the Gripper V4, the production cost was also considered alongside functionality and weight issues. Due to this, components with complex mechanisms needed to be highly reliable, such as the servo and bearings were purchased. Other parts of the gripper were 3D printed to save on cost. 3D printing also allowed us to accurately predict production costs, as material consumption and printer running costs can easily be calculated before prints were made.

By incorporating finance planning with Scrum project management, Fish Logic was ultimately able to stay within the set budget while simultaneously being able to exploit the benefits of using Scrum project management.

School Name:	Macau Anglican College			From:	01/09/2023
Instructor:	Ryan Chan	Reporting Period:		To:	22/06/2024
Team Name:	Fish Logic				
Income					
Macau Anglican College Grant					$3,600.00
Funds from selling merchandise					$286.00
Catagory	Type:	Descirption/Examples	Projected Cost		Budgeted Value
Electronics	Re-used	Blue Robotics Thruster	$817.87		USD0.00
Electronics	Re-used	Camera	$91.56		USD0.00
Hardware	Re-used	Re-used Hardware	$2,269.17		USD0.00
Electronics	Re-used	Re-used Electronics	$568.56		USD0.00
Hardware	Purchased	3D-Printer Filament and Resin	$400.00		USD400.00
Hardware	Purchased	Waterproof Plugs and Enclosures	$70.00		USD65.00
Electronics	Purchased	Electronics	$900.00		USD900.00
Hardware	Purchased	Hardware	$110.00		USD130.00
Travel	Purchased	To swimming pool	$190.00		USD195.00
Travel	Purchased	Transportation to Hong Kong	$338.00		USD390.00
Electronics	Purchased	Laptop	$1,800.00		USD1,800.00
Total Income:					USD3,886.00
Total Expenses:					USD3,808.00
Remaining Budget:					USD78.00
Total Fundraising Needed:					USD0.00

Figure 60. Budget planning table

Safety

Vehicle Safety Features

Safety Features	Description
Light	Lights are installed on the ROV for it to be more noticeable in its surroundings to avoid accidents such as bumping into other ROVs, sea creatures, or even divers.
Thruster Shrouds	IP20 standard compliant 3D printed thruster shrouds are installed onto the thrusters, which prevent fingers from getting near the propellers and sustaining injury.
No Sharp Edges	All exposed edges of the ROV and the modules are chamfered to prevent cuts and injuries during handling.
Handle	A handle is installed on top of the ROV which allows safe and unobstructed handling.
Fast Blown Fuze	Fast blown fuzes are used to cut the circuit when the current exceeds the designed limit, which can prevent accidents such as shock due to unintended conduction.
Kill Switch	A kill switch is installed in the control box to cut all power to the ROV in case of an emergency.
Notification LEDs	There are notification LEDs installed on different parts of the ROV to show that the ROV or the electronics modules are powered.

Safety Principles

In Fishlogic, safety is our number one priority. The safety of personnel, wildlife, and the environment is considered for all operations and decisions carried out during the development of Amphitrite. To achieve this, Fishlogic has adopted the 4 stages of Emergency Management: Prevention, protection, response, and recovery. Prevention is measures taken to avoid potential safety hazards and accidents. Protection is when exposure to hazards cannot be avoided but can be controlled, such as wearing safety goggles or use of protective gloves when using sharp or dangerous tools. Responses are quick and effective in case of unfortunate events. Recovery is the act of returning the work area to its original safety standards after an incident and conducting thorough analysis of how it happened and how to prevent it. New team members are briefed on the safety principles and are taught safety procedures in the workshop and at the poolside. Vehicle safety features are considered during the designing process of the ROV to ensure it meets all safety requirements.

Acknowledgements

Marine Advanced Technology Education (MATE) - For organizing this year's competition.

Institution of Engineering and Technology (IET) - For organizing this year's Hong Kong regional competition.

Macau Science and Technology Development Fund (FDCT) - For providing computers and equipment.

Education and Youth Affairs Bureau (DSEDJ) - For providing water trial and competition venues.

Macau Anglican College (MAC) - Our school for funding our project, providing workshop space and transport costs.

Mr. Ryan Chan - Our mentor for guiding our team as well as teaching mechanical design and project management.

Mr. Ryan Ip - Our lab assistant at MAC for assisting us in experiments and purchasing.
Mr. Kevin Cheong - Our mentor for teaching us all about computer science.

Fish Logic Alumni - Gavin, Isaac, Thomas, Kevin, Charles, Kimi and Venus for their help and advice.

Autodesk - For free student license software.

Our Families - For their continued support and encouragement.

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Appendix1: Safety Procedures

WORKSHOP SAFETY CHECKLIST

GENERAL

- [ ] Safety equipment including safety glasses and protective gloves must be worn for using power tools and sharp tools
- [ ] Respirator must be worn when in contact with fine particles
- [ ] Clear work area to prevent hazards (knocking things over, tripping hazard, etc.)
- [ ] Sufficient amount of tools and equipment
- [ ] Tools and equipment are properly stored
- [ ] Regular sanitizing of work and personal space

SOLDERING

- [ ] Safety goggles and mask must be worn
- [ ] Ventilation must be turned on
- [ ] Work area must be clear

HANDLING RESIN

- [ ] Ventilation must be turned on
- [ ] Prepare tissue paper
- [ ] Work area must be clear

OPERATION SAFETY CHECKLIST

SETUP ON DESK

- [ ] Area clear/safe (no tripping hazards, items in the way)
- [ ] Tether is laid out and managed by a team member
- [ ] Plugs and sockets are connected securely
- [ ] Verify power switch is off ping hazards, items in the way)
- [ ] Thrusters are properly shielded
- [ ] No exposed copper or bare wires
- [ ] Screws and nuts are tightping hazards, items in the way)
- [ ] Tether securely connected to ROV
- [ ] Single inline 30A fuse in place

POWER UP

- [ ] Ensure all 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

IN CASE OF 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