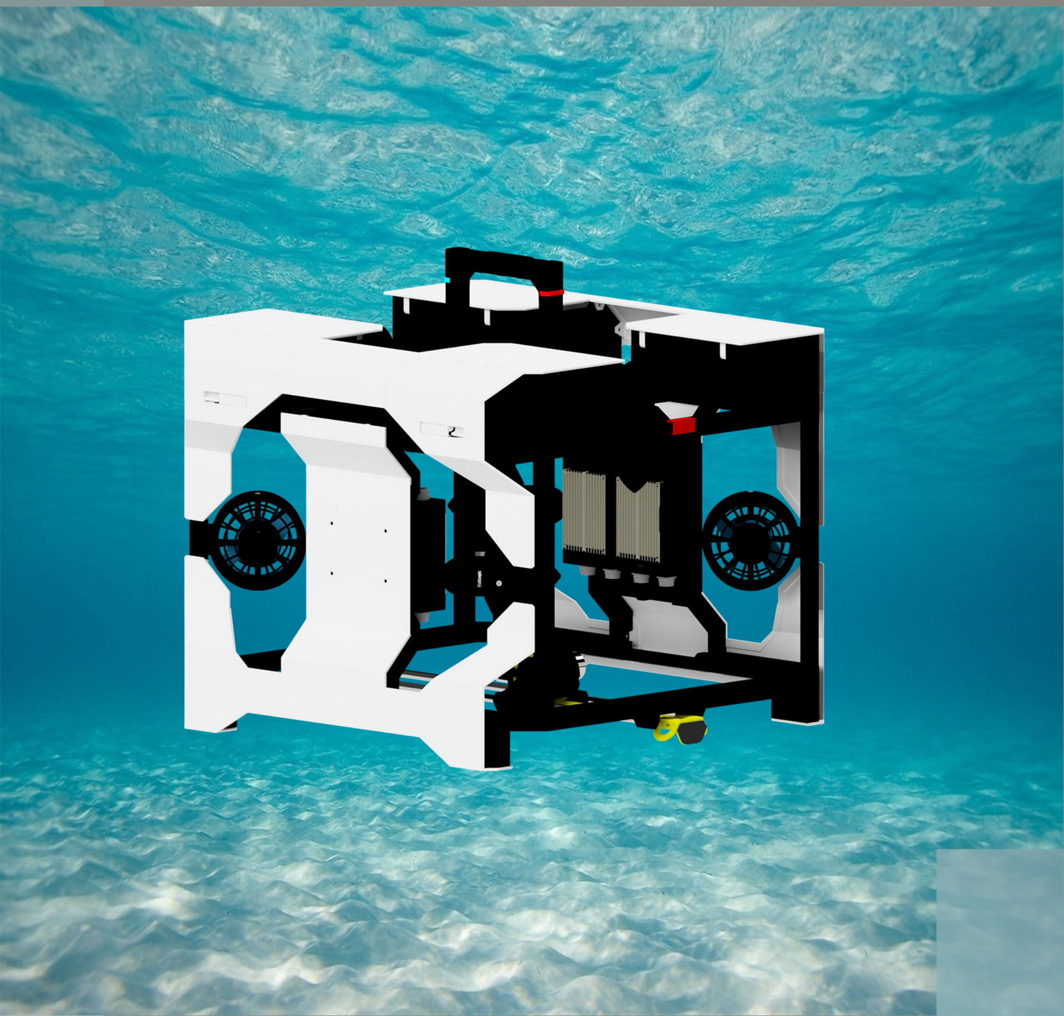
FISHLOGIC
MACAU ANGLICAN COLLEGE

Hydron



Members	Roles
Isaac Sin Wai Teng	CEO & CTO
Ada Leong Weng S am	CFO & Mechanical Engineer
Bono Lam Iat Long	Pilot
Ryan Chan Pou Ut	Head Mechanical Engineer & Safety Officer
Thomas Lei Chon Weng	Mechanical Engineer
Chester Lo Ngou Hei	Mechanical Engineer
Ryan Chan Chon In	Mechanical Engineer
Edward Lei Kuok Lon	Mechanical Engineer
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Ricky Vu Kun Seng	Head Software Engineer
Ardith Ho Wai Man	Software Engineer
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Abstract

Hydron is Fish Logic's fifth Remotely Operated Vehicle (ROV), designed on the request for proposals by MATE Center and the our wider global community, for an ROV to assist in the remediation of ocean plastics, climate change's impact on coral reefs, and the consequences of poor environmental practices on inland waterways. To meet the desired functionalities, Fish Logic, a company dedicated to developing underwater ROVs, has designed Hydron with a flexible configuration. Hydron is capable of removing plastic pollutants, determining health of, collecting samples and maintaining health of species in the coral reef and maintaining healthy waterways of Delaware.

Hydron is fully designed by the twelve dedicated members of Fish Logic. The design is a revolution of the previous ROVs' (Electro Stargazer and Blazin' Hydra) with the emphasis on prioritizing safety, followed by functionality, ease of use, ease of maintenance and ease of manufacture. Fish Logic has incorporated systems engineering in designing the ROV for better system integration with all aspects of the ROV validated through testing.

The majority of Hydron'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". Hydron was designed to meet size and weight restrictions. The resulting ROV is a high performance, flexible, reliable and pilot optimized configuration.

The development period of the Hydron encompasses 2 years with about fourteen thousand work hours. The market value of the Hydron is 27,470HKD.

Member or Fish Logic (Photo by: Justin Ngo)
Front row: Chester, Ryan, Isaac, Ada, Chloe
Back row: Edward, Chon In, Julio, Bono, Ricky, Thomas, Ardith (From left to right)

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Project Management

Fish Logic decided to use Agile project management, for its focus on continuous incremental iteration throughout the ROV development. By utilizing Agile, the team aims to achieve a working product as soon as possible which allows for immediate feedback throughout the development process and collaborative decision making. Instead of strict targets, Agile uses a broad vision established at the start of the development process, which allows for flexibility and improvement during the development phases. When presented with changes in conditions, the team is given room to easily adapt. As the development of the ROV progresses, the team narrows down on the target incrementally with more clarity. Since Agile requires frequent feedback and collaborative decision-making, it is well suited to Fish Logic's small team and transparent work culture.

Scrum is the chosen agile project management methodology, in which the team works in short bursts from 2-4 weeks called sprints. Thus the 2 year development period is divided up, plotted into a Release Planning timeline, with the length is set preferably so that each sprint ends on an event, such as an experiment date, system test date, or water test date and always requires deliverables such as a prototype part, tool, modifications or software release to be completed.

To implement scrum, there are 4 types of documents known as artifacts: the product backlog, which is a priority list of goals that covers the entire scope

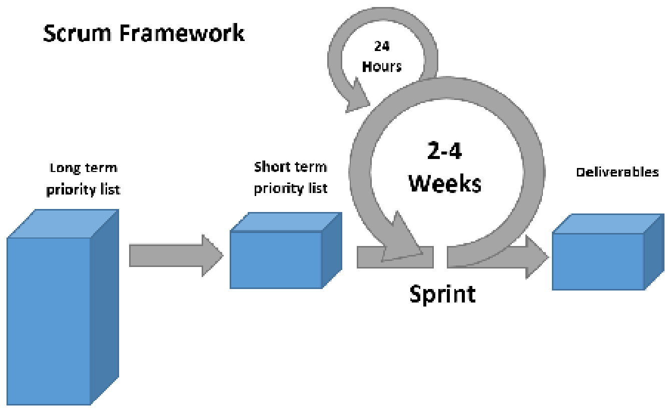


Figure 1. Scrum Framework

of the project in which the ROV needs to achieve for each sprint and the sprint backlog, developed at the start of each sprint, is a priority list of all the tasks to be completed in the current sprint. Both lists are written in a shared document on Notability. All deliverables set in the aforementioned Release Planning, are stacked into a Burn Down Chart to monitor the overall progress. The project manager, referred to as the Scrum Master selects tasks from the sprint backlog and briefs the t eam in a daily standup. Any obstacles to upcoming tasks are also discussed to be dealt with. Scrum has allowed Fish Logic to remain adaptable as schedules are often modified due to unknown water testing dates, academic work of the team members, public exams and changes in COVID restrictions.

After the end of each sprint, a sprint review is conducted to gather all data from water testing, including video footage, software bugs and feedback from the pilot. This is used in a debrief meeting to analyze problems that need to be addressed, along with discussing what tasks have

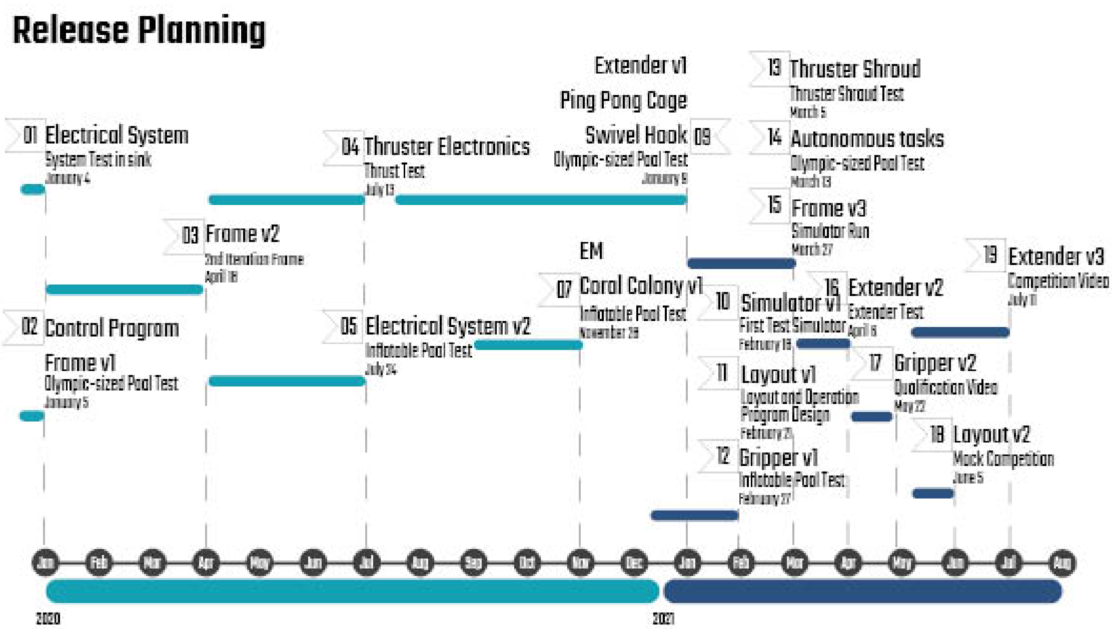
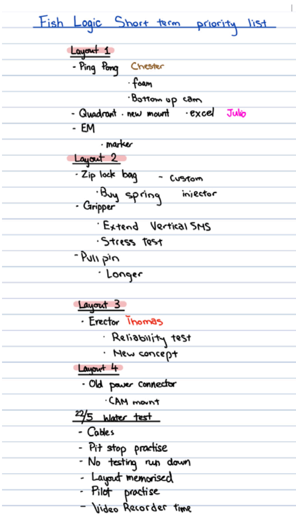


Figure 2. Release Planning From January 2020 to August 2021



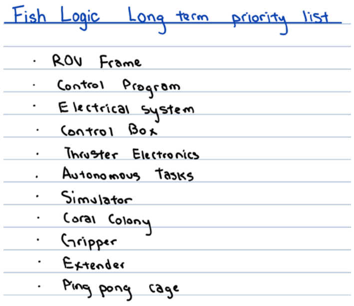


Figure 3. Long-Term Priority List (left)
Figure 4. Short-Term Priority List(right)

been completed and what work has still yet to be completed. A sprint retrospective is then conducted to inspect the working approach of the team, as well as looking for improvements in our work method for the next sprint.

In regards to resources, it is easy to lose sight of resources allocated for the project as Scrum Agile management is less structured. However, by following the resource management principle that promotes the transparency of resources to other potential users in the team, the team is able to keep track of the purchasing and allocation of materials. A spreadsheet is used to track resources of each sprint cycle with special indication to 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.

Design Rationale

Design Evolution

Fish Logic continues to use many of the features and design principles carried on from previous year, established ranging back from the ROVs: Leviathan (2017), Blazin' Hydra (2018) and Electro Stargazer (2019). The principles include 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.

In regards to safety, Fish Logic strives to ensure the safety of personnel, wildlife and environment. Functionality is evaluated by the ability to perform all mission tasks in the allocated time. Fish Logic places heavy emphasis on pilot oriented design, as good visibility, an individualized control scheme, and a custom set-up based on pilot preference

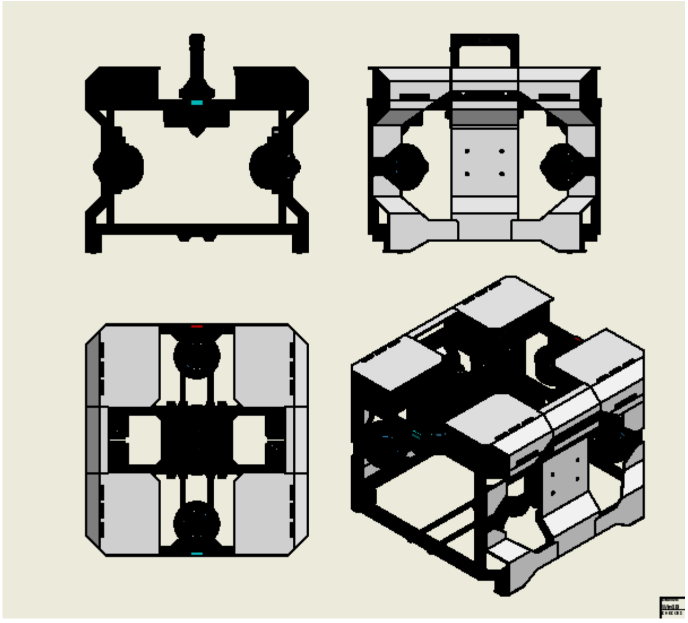


Figure 5. Blueprint of Hydron

and feedback increases the speed, accuracy and consistency of the pilot in completing the mission. Ease of use, which includes attention to ROV stability, predictability and corrective thrust vectoring adds to the confidence of the pilot. Ease of maintenance reduces the amount of down time and allows for quick return to the water after swapping tools. This is enabled by focusing on reliability, standardization and modular parts. For mechanical reliability, simpler design options are considered first, therefore passive tools are prefered to reduce the chances of component failure. Mechanical parts are standardized by the Standard Mounting System (SMS4), allowing any tools and payload with SMS4 to be interchangeable. Front-to-back symmetry of the ROV reduces the need to surface as the ROV can carry double the payload on both ends. Electrical standardization is achieved with the Universal connectors and CANBus. CANBus 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 to simplify maintenance. Electronic components are cast in epoxy to waterproof them reliably, eliminating all points of water entry. Ease of manufacturing is accomplished through the extensive use of 3D printing, which guarantees that all the manufactured parts are of consistent quality and frees up team members to focus on the design of the parts while the parts are fabricated. Fish Logic relies on the design principles to eliminate risk of technical debt build up during the design phase. Once the parts are produced, all designs will go through validation with data driven, scientific processes as well as gather 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. With the ROV tool layouts and mission program designed in conjunction with each other and according to pilot preferences, optimizing the approach to each task while minimizing the effect towards other tools on the ROV.

Systems Engineering

Fish Logic uses systems engineering processes inspired by SpaceX, due to its compatibility with Scrum Agile Project Management. Systems engineering is used to help develop safe, reliable and well-integrated systems in accordance with our design principles by anticipating and solving integration problems ahead of time. It requires the important balance between intensive preplanned systems engineering and rapid prototyping to reduce system risk, with the balancing heavily dependent on the organizational agility, cost of iteration and the ability to trade lower level requirements. The team strives to learn through experience rather than consuming schedules

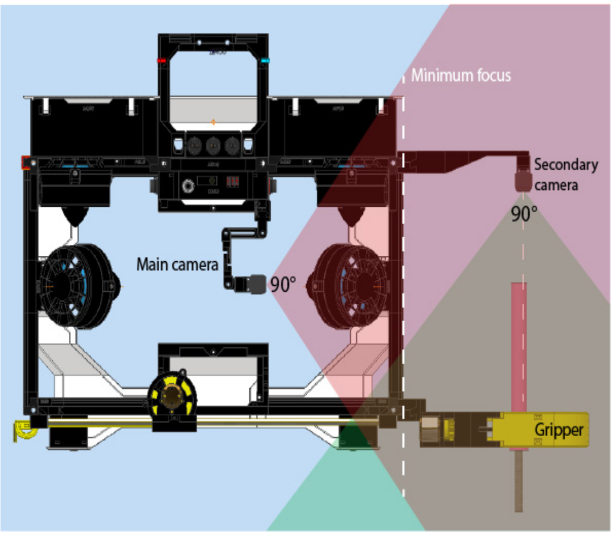


Figure 6. Systematic Process for Tool Development

attempting to anticipate all possible system interactions. To promote better systems integration, systems level tasks are distributed to departments to get departments to focus on systems thinking. Which is then reviewed by the CTO who acts as the 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 phase. This is to prevent 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 component 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. Interaction 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 the tool design is optimised 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 program can even be modified if advantageous.

Innovation

The Standard Mounting System

The Standard Mounting System 4 (SMS4) is the fourth generation of a 3D printed quick mounting system which is used for the attachment of tools and cameras to the Hydron ROV.

SMS4 consists of a detachable clamp and a rail. The SMS4 clamp secures onto a SMS rail using a single

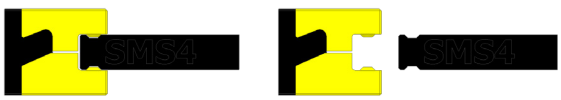


Figure 7. Standard Mounting System 4

M5 screw. Compared with the SMS3, SMS4 addresses the issues of loss of grip due to material fatigue after long term use by splitting the clamp into an assembly of 3 separate parts, reducing the stress experienced by the plastic clamp. The centerpiece of the clamp can be integrated with each ROV tool for mounting. The rail is the counterpart of the clamp that allows any tools and camera with a SMS4 clamp to be placed in precise locations along the many SMS rails on the ROV. SMS rails all around the structure of the ROV to provide ample mounting

spaces for the optimal and flexible placement of tools, as well as reducing the need to change tools due to lack of mounting space. An Aluminium hex rod can be integrated into the SMS rail, allowing the rail to also act as a structural piece of the ROV frame. Since the SMS rail has not been modified since SMS2 from Blazin' Hydra, the SMS4 clamp are backwards compatible with SMS2&3. The SMS4 clamp has been tested to be capable of resisting movement of up to 216N applied parallel to the rail.

The Micro SMS4 (mSMS4) clamp is a smaller variant of SMS4 that is used for lighter loads such as cameras and cable clips. This smaller size also allows cameras to be mounted closer to the tools while being lighter and taking up less space on the ROV.

Magnetic Camera Mounts

The Magnetic Camera Mount is designed for the quick changes in camera placement. The previous method of moving the cameras required the dismounting and reattaching the camera's SMS mount in the new location. Such a procedure requires the precise use of a screw driver and more than 30 seconds in time. Moving the camera would also need adjustment of the camera mount to the correct angle. With magnetic camera mounts, separate camera mounts can now be placed at the locations where camera angles are needed and can be tightened down to correct camera angle. Camera relocation just needs decoupling and attaching to another magnetic mount, without the need of tools and can be performed in under 3 seconds. The magnet enclosure is designed to be box shaped to prevent rotation and the mounts are produced to a running fit tolerance to avoid any unwanted vibrations of the camera. This also ensures cameras can only be detached by a pulling force normal to the mount. The attraction force of the Magnetic Camera Mount is 10N.

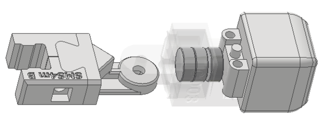


Figure 8. Magnetic Camera Mount

Simulator

Fish Logic over the years 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 developed a ROV simulator 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 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. The simulator has since influenced the design of the ROV shape and thruster placements, by exposing problems earlier in the stages of development, allowing for a more rapid and smooth prototyping process. 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 situation. By utilising 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

Mechanical

Propulsion and Vehicle Dynamics

Fish Logic, using the new ROV simulator, established the baseline requirements for the ROV by examining the mission tasks, as well as the performance needed to complete all mission tasks within the provided time. Thus determined that the ROV required 5 degrees of freedom (DOF) and a minimum speed of 0.6m/s.

Blue Robotics T100 and T200 are the thrusters of choice, for its powerful yet compact design. In order to make the thrusters a modular component, Fish Logic decided to integrate all the thruster electronics onto the thruster. To achieve this, the thruster's electronics housing is designed to fit the streamlined profile of the thruster. This required the use of MSLA (Masked Stereolithography) resin 3D printing in order to produce the reduced the wall thickness (1.2mm) of the shell to fit all electronics to the same width of the thruster motor and allow it to attach onto the existing screw mounts, without any modification to the rest of the thruster. For CAN bus electronics, microprocessor and ESC to fit inside the 3D printed enclosure, it necessitated the use of a custom printed circuit board with surface mount devices. Transparent epoxy is used to waterproof the electronics by filling the housing with the additional benefit of allowing indicator LEDs on the PCB to shine through.

A Vectored Thrust Configuration was chosen with 4 Blue RoboticsT100 thrusters placed at 45 degree steering angle that exert forces in the horizontal plane allowing horizontal translations and rotations around the yaw axis. 2 Blue Robotics T200 are used as vertical thrusters for vertical movement and rotation, with a rated combined lifting force of 56N. The ROV has a recorded maxiumum speed of 0.63m/s, meeting the performance requirements.

In the first water test, the Hydron prototype produced unintended upward motion when maneuvering. Upon further investigation, this was caused by the ROV producing upward pitching motion during lateral acceleration. With the ROV simulator, the same pitching movement was replicated in the physics engine. Consequently, It allowed us to identify the cause, indicating that the center of thrust misaligned with the center of gravity. With optimum thruster placement realigned to the center of gravity to the center of thrust, an adjustable test rig was adapted to the ROV structure to replicate the setup in the simulator. As predicted, the simulator setup correlated to real world data. With the new thruster placement height, no more unintentional pitching is observed when accelerating.

Vechicle Structure

Hydron frame is a 3D printed structure made of PLA+, strengthened by 7mm aluminium hex rods. Since the SMS4 rail both allows for tool mounting and can be used as structural support, it has been integrated along all the straight edges of the frame, maximizing the mounting space available and flexibility allowing tools and cameras to be placed at any precise location along the available SMS rails.

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 relatively small increase in manufacturing difficulty, structural parts of the ROV can serve additional functions such as aforementioned mounting for tools and cable management. Through the process of settling the layout and placements before

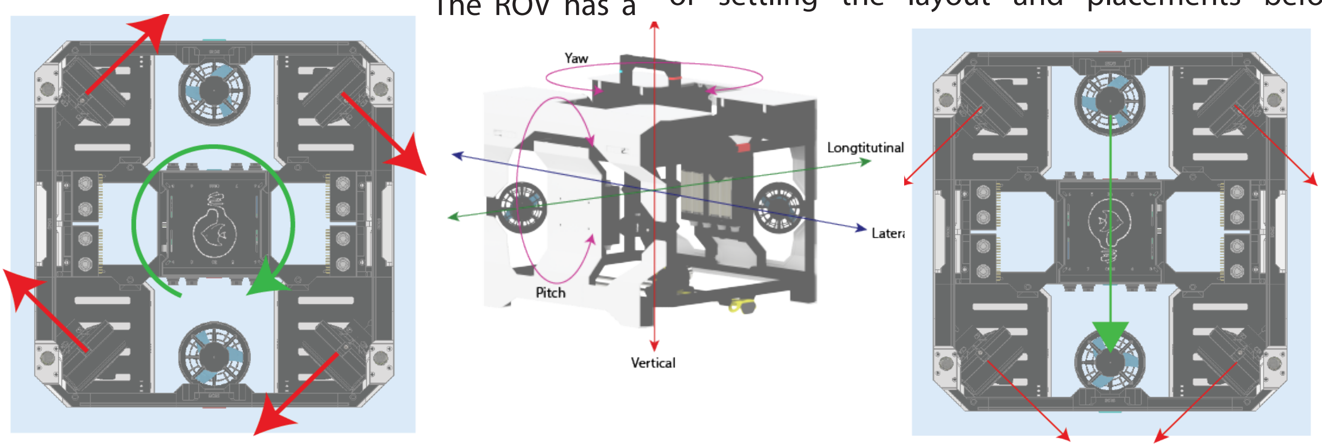


Figure 10. 5 Degrees-of-Freedom produced by 6 Thruster Configuration

SID

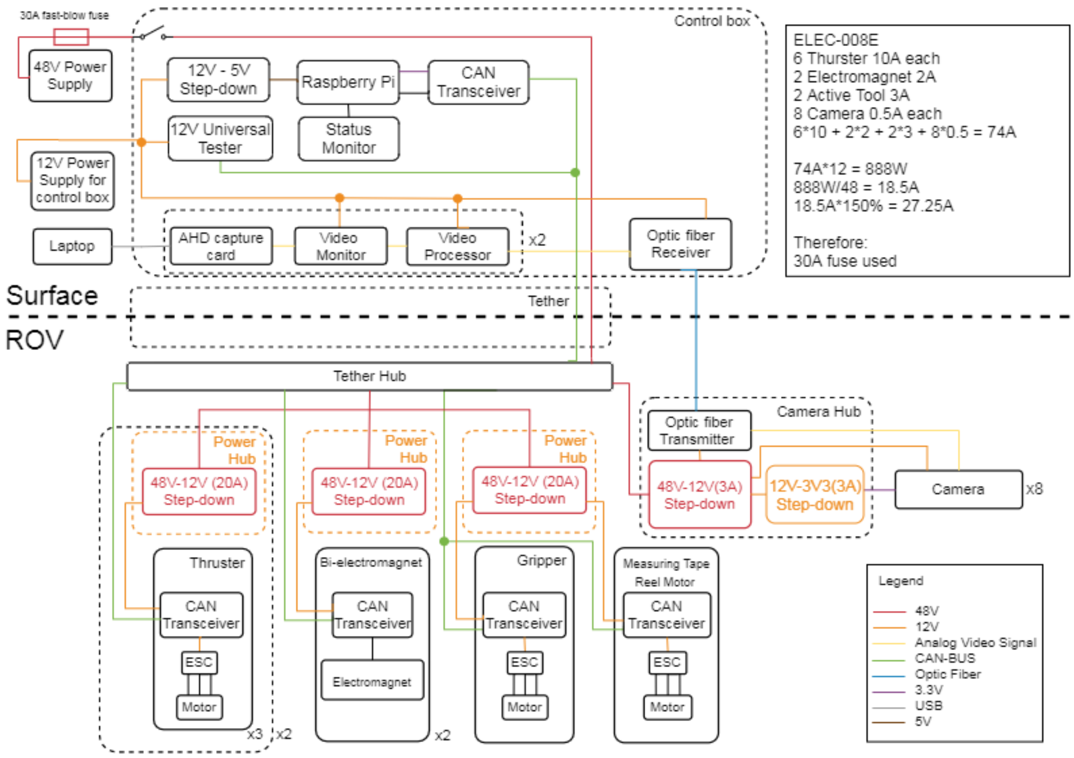


Figure 11. System Integrated Diagram (SID)

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 of 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 contact of external elements to potential hazards on the ROV. The adoption of integrating hollow aluminium hex rods within the 3D printed frame, has allowed the frame to be much thinner and stronger compared to Electro Stargazer all while without compromising on the weight of the ROV. This has resulted in reduction in hydrodynamic drag and faster acceleration in water. Individual parts of the Hydron frame are made to be modular, this allows parts to be easily upgraded and swapped out in case of damage, therefore improving the ease of maintenance of the ROV.

Material Choice

Manufacturing Techniques						
3D Printing					CNC	
Advantages: More efficient, only uses the amount of materials that make up the object that it is printing Easy to print and operate Parts produced are lightweight, ideal for ROV Disadvantages: Slower, printing layer by layer can take hours for a small part Limited material selection					Advantages: Typically faster in large-scale manufacturing Wider material choice Disadvantages: Less efficient, uses more material then needed Process is much more expensive	
Materials	**PLA**	**PLA+**	**ABS**	**XT(PETG)**	**Aluminum**	**Iron**
Density(g/cm3)	1.24	1.24	1.04	1.2	2.7	7.874
Elongation at break (%)	5	29	22	228	12	0.52
UTS (MPa)	71	60	43	49	276	275
Ease of Manufacturing			Difficult to print. Warping issues, and produces toxic fume requiring a	Difficult to print. High heating temperature. Warping	Difficult to mill. Lack of in house 3D milling	Difficult to mill. Lack of in house 3D milling

Figure 12. Comparison of different manufacturing techniques and materials

The extensive use of 3D printing defines the selection for the material choice, as 3D printing allows for designs to have less restrictions from subtractive manufacturing processes such as CNC milling and produces less waste. Additive manufacturing allows us to create prototypes rapidly, therefore boosting workflow and allowing fast paced innovation. Moreover, the advantages of weight-saving, complex geometric designs from 3D printing can be exploited to maximize the functionality of each component. PLA+ from eSUN is the choice of material for all the fused filament fabrication (FFF) 3D printed parts on the Hydron. PLA+ is a blend of PLA, it has a higher elongation at break and is therefore less likely to crack, while still having ease of print and print quality offered by PLA. An additional benefit of using PLA+ is that, along with regular PLA, it is a biodegradable thermoplastics which has a lesser impact on the environment as they can be broken down by bacteria after it has served its purpose. For the Hydron ROV, aluminium rods are integrated into the frame to increase structural integrity resulting in a thinner yet stiffer frame. Mask Stereolithography (MSLA) resin 3D printing is used to make small precise parts including the thruster electronics housing as it is able to print with a small layer height for smooth outer surface. MSLA also allows printing of thin perimeters (0.1mm) to maximize volume inside the housing for electronics. However the resin is brittle (low elongation at break), low impact strength and low heat deflection temperature compared to PLA+ printer parts.

Bouyancy and Ballast

To ensure ease of use of the ROV for the pilot, our aim for the buoyancy of the ROV is for the ROV to stay upright and to maintain its depth . To achieve this, the average density needs to be as close to the density of water as possible (neutral buoyant). High density PU foam is used to provide upforce to counteract the weight of the ROV in water by trapping the less dense air in its structure. The foam is cut into chunks of a few standard sizes, which can be fitted into any of the four foam chambers situated at the top corners of the ROV to provide a high center of buoyancy. The adjustment of buoyancy is done by opening the upward-facing lid on a chamber and adding or removing chunks of foam. The size of the foam chambers is designed to house enough foam to offset the weight of the Hydron with additional capacity to account for extra payloads.

25mm Stainless steel ballast balls (64g each) are added to the bottom of the ROV in each corner. This lowers its center of gravity while additionally supporting it whe landing on a surface, allowing it to roll on the pool bed.

The distance between the low center of gravity and high center of buoyancy produces a restoring force so that the ROV tends to stay upright in and above water. This, combined with its neutral buoyancy results in a relatively stable ROV that approaches the above criteria.

Electrical system

Power Distribution

Hydron operates at 48V DC, since the ROV thrusters and tools operate at 12V, 4 power hubs are used. 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. The Camera Hub has an internal 48V to 12V step down, independent from the four 48V step down modules used for thrusters and payload, this is done to prevent noise induced from the thruster from affecting the analog cameras.

Power Hub

Each of the four Power Hubs serves as a 48V to 12V step-down. 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 via 2 screws, a replacement can be swapped quickly in the unfortunate circumstance of a Power Hub failure.

Tether

Power tether uses a pair of 2.5mm^2 RVV cable rated for (current). They are chosen as it contains a PVC Sheath layer outside which can enhance the mechanical strength of the wire and protect the cable from corrosion and mechanical damage. Signal tether uses a 0.15mm^2 TRVVPS cable which are shielded twist pair cables and are chosen due to its immunity to interference, t reduces cross talk between neighboring pairs, the shield also reduces electrical noise from affecting the signal. 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 the previous Electro Stargazer's (XXkg) tether down to (XXkg).

At first Fish Logic decided to purchase a neutral buoyant tether, with the consideration that the continuous foam sheath can reduce the chance of entanglement and would reduce the time needed to manually tune the tether buoyancy. However, the foam sheath is too rigid as kinks on the tether would cause the ROV to rotate in the water. A second PVC cable was bought to address the problem of flexibility, the attempt was to select a single thin cable that carries both signal and power, with the buoyancy of the tether later offset with added float. The cable turned out to have even greater stiffness. Finally, through more intensive research about cable types, it was later understood that the material choice of the protective sheath around the copper wire dictates the flexibility of the tether and is the determining factor for the choice of tether cables, not just the thickness or buoyancy of the tether. The current tether sheath materials consist of a blend of PVC with a separated RVV cable for power and a TRVVPS cable for signal.

Stress relief of the tether on the ROV is secured by a tether clamp that constricts the outer insulation of the power cable to prevent any mechanical forces applied to the cable be 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.

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

1. Never pull on the tether..

2. A clean and organized workplace is a safe and productive workplace.

3. Tether is turned in the same direction to the ROV. Minimizing the number of tether turns while operating will enhance maneuvering. Remove all turns 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 is at the end of its tether, there may not be enough slack to allow an easy turn-around to follow the tether out. In this case, reverse direction to generate slack, and turn the vehicle around to manage the tether.

6. Attention must be paid to objects standing vertically or horizontally in the water column, such as the power cable for old and new power connector

7. When operating in an area containing obstructions or obstacles that could snag or foul the tether, the operator should endeavor to remember the route taken to get to any one position.

8. If the tether does become entangled, do not pull the tether to free it.

Connectors

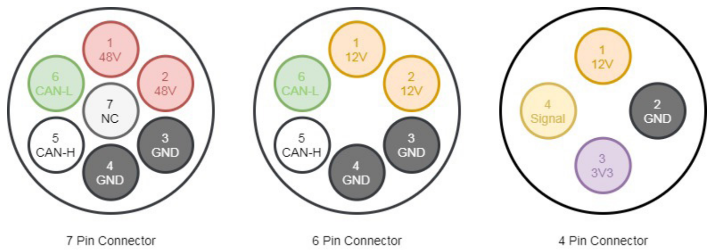


Figure 13. Universal Connectors

The connectors on the Hydron are standardized using Weipu connectors; it allows components to be connected to different sockets of the same type. Signal and power are integrated into a single connector to allow for quick swap of components. Since the manipulators and thrusters are all 12V, 6 pin Weipu SP13 connectors are used to connect to any of the Power Hubs. To prevent accidental mix up, 7 pin Weipu SP13 connectors are solely used for 48V components, while cameras use 4 pin Weipu connectors. Because each pin is only rated 5A current, 2 pairs of pins are used for power and ground, so the manipulators and thrusters can get sufficient current. Although the connectors claim to be waterproof, the back of the connectors are filled with epoxy and Silicon grease is used between the pins and socket to prevent water leaking into the connector.

Camera system

Figure 14. AHD Camera

Hydron is equipped with 8 cameras, 2 of which are main cameras facing the front and rear of the ROV for navigation as the ROV is capable of inverting the driving direction. The transition to Analog High Definition (AHD) cameras instead of the previous analog cameras stems from the higher resolution of the cameras, from 480p to 720p, 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 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 camera hub for 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 helped to significantly reduce noise impact from thrusters and the surrounding environment compared with using copper wires for signaling.

Control System

CAN Bus System

CAN bus is the communication protocol used in Hydron. It is the key for Hydron to achieve standardization. Along with universal connectors, CAN bus allows onboard components to be connected from anywhere on the network, allowing Hydron's configuration to be flexible, modular and simplifies its circuitry and assembly. Thus contributes to the ease of maintenance as well as enables future upgrades and expansion of the system.

CAN bus was chosen over other alternatives mainly due to the durability and robustness of the network protocol, with features such as error checking and being less susceptible to noise, it is an ideal communication protocol on a ROV. Compared to I2C, an alternative bus network used in previous Fish Logic ROVs, the Hydron CAN bus has experienced much less of the stability issues found in previous I2C implementation in Electro Stargazer, where errors increase as messages are sent more frequently leading to occasional program failures.

The Hydron's CAN bus network expands across the tether all the way to the control box which runs the control program, allowing a direct connection to all nodes on 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 our 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. To allow individual thruster and active tool control, the message frame is manipulated to allow node specific communication. Messages from thrusters are also prioritized to maintain smoothness in control while messages that are sent back from nodes, such as temperature and voltage data, are less prioritized.

Control Programme

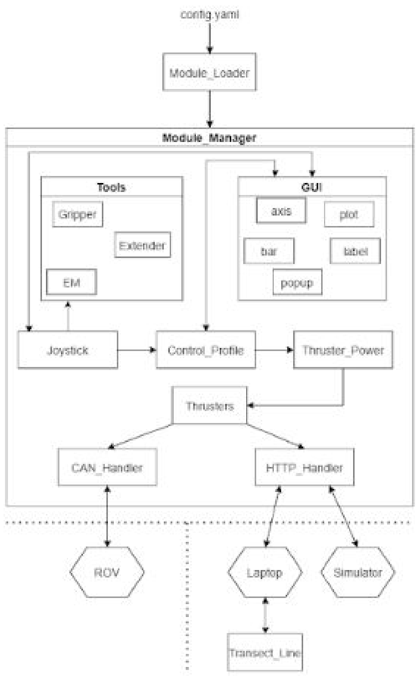


Figure 15.Module diagram of the control program

Control_Profile	Changes the handling of the ROV by modifying max power and sensitivity
Thrusters	Ensures gradual acceleration of thrusters and compose data using thruster ID
CAN_Handler	Sends any data to the physical ROV system using the CAN protocol
HTTP_Handler	Sends and receives any data between the current device and another(ex. laptop). Used to connect the control program to the simulator for test drives. CV intensive processes can be run on a separate device and pass the control values to the control program.
Module_Loader	Loads preset values from configuration file and construct Modules

Figure 16.Functions of modules in the 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.

Thruster Power Mapping

After the control software receives movement command inputs, the input values will be processed into a 6 dimensional vector with elements ranging from -1 to 1:

$$B = \begin{pmatrix} Drive \\ Strafe \\ Yaw \\ Updown \\ Tilt\ front-back \\ Tilt\ left-right \end{pmatrix}$$

The Moore-Penrose pseudoinverse is used in calculations to map ROV movement direction to thrust power of each individual thruster.

By measuring the position and direction relative to ROV's center of mass, a matrix can be constructed that represents the contribution of each thruster to each DoF.

$$A = \begin{pmatrix} Dir-X_{FL} & Dir-X_{FR} & Dir-X_{BL} & Dir-X_{BR} & Dir-X_{UF} & Dir-X_{UB} \\ Dir-Y_{FL} & Dir-Y_{FR} & Dir-Y_{BL} & Dir-Y_{BR} & Dir-Y_{UF} & Dir-Y_{UB} \\ Dir-Z_{FL} & Dir-Z_{FR} & Dir-Z_{BL} & Dir-Z_{BR} & Dir-Z_{UF} & Dir-Z_{UB} \\ T-X_{FL} & T-X_{FR} & T-X_{BL} & T-X_{BR} & T-X_{UF} & T-X_{UB} \\ T-Y_{FL} & T-Y_{FR} & T-Y_{BL} & T-Y_{BR} & T-Y_{UF} & T-Y_{UB} \\ T-Z_{FL} & T-Z_{FR} & T-Z_{BL} & T-Z_{BR} & T-Z_{UF} & T-Z_{UB} \end{pmatrix}$$

key:
- Dir - direction
- T - torque
- FL - thruster front-left
- FR - thruster front-right
- BL - thruster back-left
- BR - thruster back-right
- UF - thruster up-front
- UB - thruster up-back

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

$$Ax = B$$
$$A^{\dagger}Ax = A^{\dagger}B$$
$$x = A^{\dagger}B$$

where

Ax is the Moore-Penrose pseudoinverse of matrix A

A is the 6x6 matrix mapping thruster contribution and DoF

B is a 6 dimensional vector containing the movement command

x is the resultant 6 dimensional vector containing required power of each thruster

key:
- FL - thruster front-left power
- FR - thruster front-right power
- BL - thruster back-left power
- BR - thruster back-right power
- UF - thruster up-front power
- UB - thruster up-back power

Calculation with matrices and vectors is chosen as opposed to hard coding the calculations for each thruster's power individually because the code is more concise and it can be extended to suit a wider range of scenarios. 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.

Control Box

Figure 18.Control box

The control box is built inside a custom made protective splash-proof case. The size of the control box was catered to fit the two 15.6 inch monitors mounted on the lid with each monitor providing the pilot with four different camera views. The bottom portion of the box contains a main control panel that covers the electronic modules and wiring to prevent accidental contact. The panels are secured by two aluminium extrusion racks that can be separately lifted up, which allows for speedy inspections, maintenance and troubleshooting. The control panel is divided into individual standardized modules, with each module dedicated to housing electronics of the same functions. This allows electronics in the control box to be easily interchanged when there are design changes and requires new modules to be added in. A module called the Pi Crust houses a Raspberry Pi that runs the ROV program, as well as a touchscreen that displays the status of the ROV using a custom GUI. In case of any emergencies, a built-in kill switch can cut all the electricity to the ROV.

Mission specifics

Bi-Electromagnet

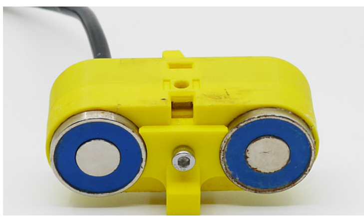


Figure 17.Bi-Electromagnet

The Bi-Electromagnet (BEM) is a general purpose tool used in reconnecting the new power connector, removing plastic debris, transporting the injector for sea stars, transporting the quadrat and placing the eel trap.

The choice to use electromagnets was due to its simple working principle with no moving parts making it to manufacture, maintain and use, while being reliable and versatile for many tasks.

Each BEM consists of two individual electromagnets which are positioned next to each other. Hydron, equipped with two BEM, has a total of four electromagnets that can be individually turned on and off, thus giving it the capacity to hold four objects simultaneously. The center point between the two electromagnets are spaced apart to the width of the U-bolt present on the eel trap in order to ensure a secure contact. The two electromagnets on the BEM are rated for a combined force of attraction of 36kg. The use of electromagnets are chosen due to its reliability and ease to waterproof since there are no moving parts therefore mechanical parts can't wear out and components are easy to be epoxied.

An onboard motor driver allows polarity of the electromagnet to be reversed, this prevents light ferrous objects that are magnetized to remain attracted to the BEM even when the electromagnet is switched off, especially with tasks such as the injector for sea star that are particularly prone to this effect. Multiple mounting points are located around the BEM, this allows tools such as the Ziploc bag grabber to be mounted on it.

Gripper

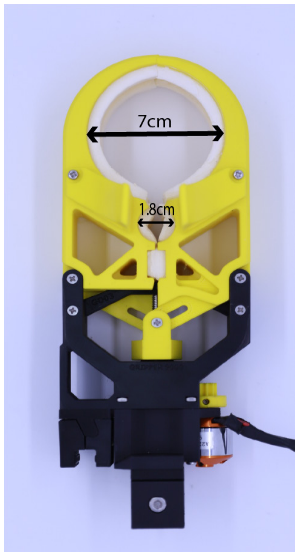


Figure 19.Gripper

The Gripper is a double-pivot claw that is designed as a general purpose tool with specialized grip surfaces for the transportation of mesh catch bags, the relocation of coral fragments, as well as the retrieval of a sponge section.

The Gripper uses a brushless motor for articulation due to its ease of waterproofing. The drive gear of the motor is reduced by the ratio of 1:3 to increase torque to the linear rod gear. The linear rod transfers the rotational motion into a linear motion that articulates the jaw.

The double pivot claw configuration was chosen as it is relatively mechanically simple compared to the linear and adaptive gripper prototypes that the team has tested, without compromising in capability in accomplishing its designated tasks. The gripper jaw is divided in sections where each surface serves a different purpose. The front of the claw is shaped like jagged teeth for the retrieval of ziploc bags. The large semi-circular surfaces are for collecting the sponge sample and the smaller surfaces are for holding onto corral fragments and mesh catch bags. The remaining flat surface is intended for general use. Bracket extensions attached to the top of the jaws to prevent unwanted rotation of the mesh catch bag for easier installation. The opening and closing speed of the Gripper is adjustable up to 70°/s and can hold onto objects well exceeding the weight of 5N in water.

Swivel Hook

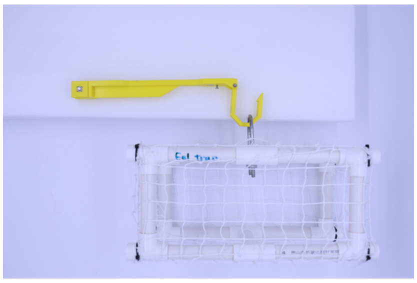


Figure 20.Swivel hook

The Swivel Hook is used for the retrieval of the mesh catch bag and eel trap. The hook is held horizontally by magnets but pivots downwards when lifting up the caught object, making it difficult for the object to fall off. The force needed for the swivel hook to be released downwards is adjusted to 35g, which is the weight of the mesh catch bag in water as it is lighter than the eel trap.

Task 1

Old Power Connector Clasp

Figure 21.OPC Clasps

The Old Power Connector Clasp is a Y-shaped tool with a magnetic clasp that latches onto the neck of the Old Power Connector (OPC). While a passive hook with no moving parts is able to lift the OPC, any quick movement of the ROV would cause the OPC to fall off the hook. Subsequently a Y-shaped design was chosen, with a flap held open by repelling magnets that act as a trapping mechanism. When capturing the OPC, the flap mechanism is pushed aside to let the OPC pass, once it clears the flap, the flap reopens and secures the OPC in the tool. A vertical board behind the tool opening helps prevent rotation of the trapped OPC from falling through the tool. The two magnets produce a repelling force on the flap of XXN.

New Power Connector

Figure 22.NPC

The New Power Connector (NPC) supplies power to the seabin.There is a steel washer on the top of the NPC which the ROV can hold using the EM.It has a chamfered bottom so it is easier to insert into the seabin. There are some holes around the bottom, so the NPC will not hold water when surfacing, it also reduces the drag caused by the NPC in the water, allowing it to be more secure when carried by the ROV. The NPC power cable is routed furthest away from the attachment point to minimize the chance that it can be tangled with the ROV. The NPC is bottom heavy so that the NPC can always remain upright. It also has some pink LED lights to indicate if the power is connected.

Surface Debris Collector

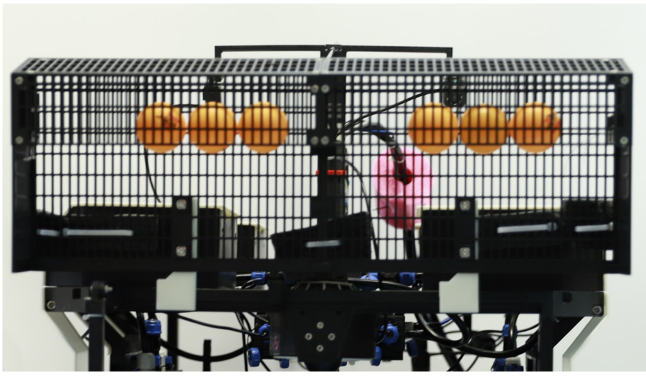


Figure 23.Surface Debris Collector

The Surface Debris Collector is a wide rectangular cage, mounted on top of the ROV facing forward. It is a passive tool that collects floating plastic debris, ping pong balls, as the ROV moves forward. As the ROV descends, it traps the debris into the cage by forcing the pair of fishing lines onto the debris. The debris is now trapped in the collector as the tension of the fishing lines is too strong for the debris to escape.

In order to trap the ping pong balls that are 40mm in diameter, the fishing lines are spaced 30mm apart. To easily adjust the tension, the two fishing lines are attached to an anchor and a screw tensioner on the collector. The tension of the fishing lines is set at XXN, it allows the ping pong ball with an upthrust of 0.328N when underwater to force apart the strings. of tension in the fishing line. The debris is now trapped as its weight of 0.027N is not enough to fall through between the fishing lines.

The ping pong cage is 480mm in width, same as the width of the ROV to maximize the frontal area able to collect ping pong balls. Based on pilot feedback and training data, two cameras are mounted on a forked camera mount, which is in a central position and on top of the ROV. One more camera is mounted on the bottom rail of the ROV looking directly up into the trapping mechanism for alignment purposes. To protect the exposed cameras from the surface debris frame, a carbon fiber rod bridges between the collector and the forked camera mount. The collector's cage-like structure allows for the accumulation of surface debris in the cage. Its gridded pattern of rectangular holes reduces weight of the collector while providing better visibility. The angle top to prevent debris getting stuck above and directs them to the front of the collector for capture.

Ghost Net Pin Magnet

Since the Ghost Net Pin is ferrous, this property can be exploited by a magnet to remove it from the Ghost Net. The magnet in the tool is a 40x20x10mm Neodymium magnet, it is protected by a 3D printed shell and has a SMS4 clamp integrated to mount the magnet tool to any of the SMS rails on the ROV.

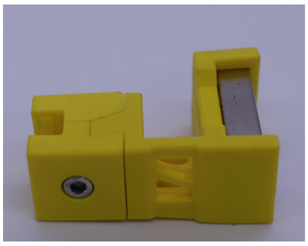


Figure 24.Ghost Net Pin Magnet

Ziploc Bag Clamp

Ziploc bag clamp is used to retrieve plastic debris from the bottom, this is done through grabbing the PVC pipe in the plastic bag. The clamp is secured on the Bi-Electromagnet, with one side held open with an activated electromagnet. The other half of the clamp is mounted onto the bottom SMS rail that acts as a shovel to push the PVC pipe in place before the clamp closes down to secure it. The clamp provides (XXN) of clamping force to ensure that pipe remains secured after capture when being transported to shore, this is achieved through using a 6 coil torsion spring made with 1.5mm diameter carbon steel rods. The clamp is designed to be placed at the bottom of the ROV only requiring the ROV to move forward to approach the Ziploc bag on the pool bed, thus not requiring the use of the vertical thruster for the task, as any downwash from the vertical thruster would carry the Ziploc bag away due to its low weight.

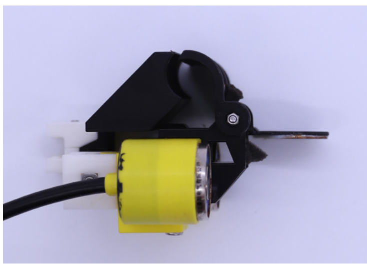


Figure 25.Ziploc bag clamp closed

Task 2 - The Catastrophic Impact Of Climate Change On Coral Reef

Fly Transect Line

The transect line is flown using the ROV bottom camera guided by computer vision. Color filters and masks are applied to the camera footage to extract the blue bounding lines only. Then Hough Line Transform is used to acquire angle of the lines. The program measures the angle from the ROV centerline to the average of the angle of the two bounding lines to determine if horizontal rotation should be applied in order to stay on course. The height of the ROV is maintained with the program adjusting the height relative to the gap constant between the two lines as observed by the camera. Forward force is constantly applied while movement is kept slow to prevent overshooting. The resultant movement command will be processed using the pseudo inverse algorithm to determine actions of each thruster.

Mapping Point of Interest

You Only Look Once version 5 (YOLOv5) machine learning model is a type of Deep Convolutional Neural Network (DCNN), it is used to map points of interest within the coral reef.

DCNN is the chosen solution over traditional computer vision due to its ability to accommodate for changes in conditions underwater with multiple objects. This is done through automatically learning important features of the image such as shape, size and color. The difficulty with the traditional approach is as classes to classify increases, feature extraction becomes more demandingmore cumbersome and parameters have to be constantly fine tuned. YOLOv5 is chosen due to its having faster inference speeds and higher mean average precision compared to other DCNN deep convolutional neural networks. The medium size model, YOLOv5m, provides a good compromise between computing power required and average precision, able to achievinge 12 FPS with a laptop with a GTX 940M graphics card. During operation, fFootage from the on board camera is sent to a laptop on shore in real time, this is done since the onboard Raspberry Pi in the control box does not have the necessary processing power.

In order to output a final image that shows the points of interest on the coral reef on a grid, the borders of the transect line is determined with line detection of the relevant colors and it is combined with the coordinates of the species detected with YOLOv5.

Coral Colony

Coral process flowchart

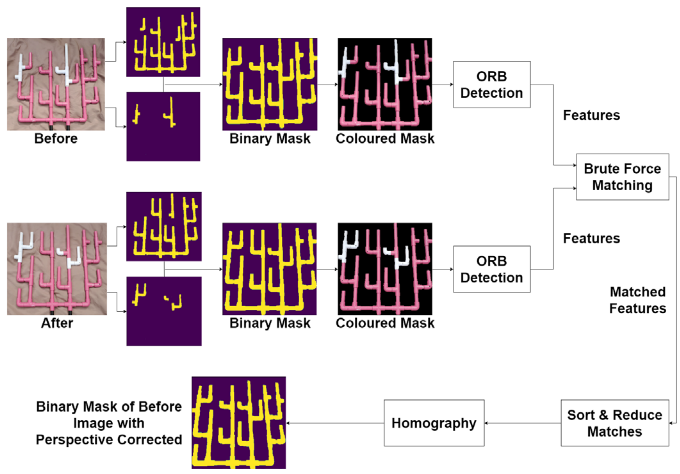


Figure 26.Image Processing Flowchart

Oriented FAST and Rotated BRIEF (ORB), that includes features from accelerated segment test detection, are used to find matching points of the coral colony before and after changes, as well as adjusting the masks of the images. The ORB detection algorithm was chosen as it does not alter the original image too much, uses feature detection and matching to compare the images, similar to the way humans analyse pictures. ORB detection uses less steps, making it faster, more efficient in using computing resources and accurate compared to Skan Skeletonize in finding the number and direction of branches of each point.

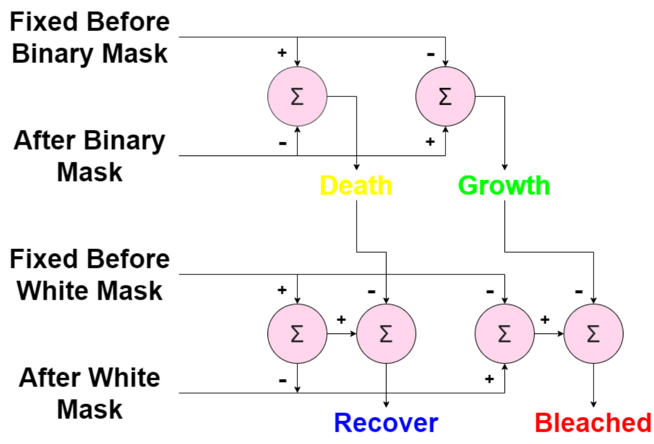


Figure 27.Determining Changes of the Coral

Figure 28.Result

Injector Device

Two Injectors are carried by the electromagnets for injecting the sea stars. The attached PU foam prevents it from resting downward on the metal washer if accidentally dropped, allowing it to be retrieved and reused.

Task 3 - Maintaining Healthy Waterways II: Delaware River and Bay

Extender

The Extender is designed for the retrieval of the sediment sample from a tunnel. It is a motorized closed case measuring tape that has a maximum extension range of 5 meters. The end-plate of the tape has a sled with velcro attached at the front that sticks to the velcro on the sediment sample for retrieval. The use of a sled reduces contact friction with the wall of the drain pipe and allows the tape to reliably extend across the full length of the corrugated pipe.

This design was chosen over using a Micro-ROV due to its smaller size, lighter weight, lower cost and as well as being able to consistently retrieve the sediment sample in a shorter amount of time. The mechanism of the measuring tape reel is driven by a brushless motor that drives a gear train which amplifies the torque of the spinning reel by 1:16 so that it can reliably push the tape against friction of the walls. The Extender is capable of an extension and retraction speed of 0.38m/s, which results in an optimal task completion time (with a tunnel length of 3.2m) of 16.8s from start of tape extension to full retraction with sediment sample acquired.

Figure 29.Extender

Quardrat

Quadrat is made with 4mm diameter carbon fiber rods with 3D printed joints to connect the rods. Carbon fiber was chosen due to its lightweight and stiffness, keeping the change in buoyancy of the ROV after deploying the quadrat to be minimal. It is attached to the Hydron before release using the Bi-Electromagnet and two hooks. Calculation of filtration rate of the mussels is done with an excel spreadsheet, where size of mussel bed and filtration rate of a mussel can be entered to calculate the overall filtration rate.

Subway

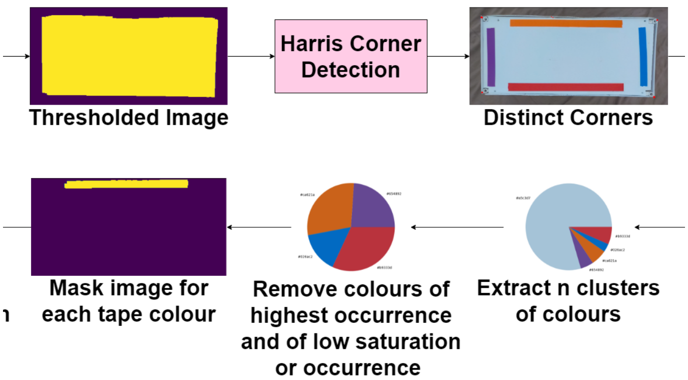


Figure 30.Flowchart of image processing and position determination of each color

The KMeans algorithm from the sklearn's cluster library was used to detect and extract colours using their HSV values. n = 5 is passed in as the parameter, where n is the number of clusters to be found.

The top side of the subway will be used as the guide for stitching the images together, which is found by finding the only side with four colours successfully extracted. For each colour on the top side, the hue value will be compared with each of the tape colours positioned at the top of each of the remaining sides to find a matching one.

Figure 31.Final result

In-house-built Vs. Commercial Components

Fish Logic fabricates 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's fabrication capability is considered on whether or not it is feasible for the members to build the part. Devices with complicated functionality, which exceeds Fish Logic's fabrication capability, such as cameras, monitors and the gamepad are purchased.

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

For the case of the thrusters, the commercial T200 thrusters have excellent performance, however there are no commercially available CAN bus transceiver modules that are small enough to fit within the ESC housing of the thruster, therefore a custom PCB is designed and sent to a manufacturer to be printed. This results in a CAN bus transceiver that is compatible with an arduino microcontroller and small enough to fit within the ESC housing to be waterproofed.

New or Reuse Components

Fish Logic strives for continual innovation and brings improvement to all aspects of the ROV. The decision on whether the parts are 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 Hydron's components are new, as only thrusters and cameras are refurbished to be compatible with the new systems and criteria. With the introduction of CAN bus protocol, all thrusters and active tools from Electro Stargazer are no longer compatible with Hydron's, some parts such as Blue Robotics thrusters are salvaged and reused, however most electronics are casted in epoxy and cannot be easily salvaged.

Testing and Troubleshooting

Vechicle Testing

In regards to testing, Fish Logic testing principles are followed: Design a testable system, test like you fly and test what you fly. Rapid design-build-test cycles that maintain a continuous design heritage are to inform the next design by the experience gained.

Documentation and testing process becomes more formal as the system matures. Tests are categorized into development, qualification and acceptance tests. Development tests used to determine hardware capability in excess of requirements and to find weaknesses such as 20 meter water pressure test, ultimate strength tests etc. This is to test reliability in different scenarios and gather important data, including: video footage, forces and power draw etc. Qualification tests demonstrate hardware performance limits, where components are tested within 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. All components are acceptance tested before 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.

Troubleshooting Strategy

During one of the ROV Hardware in the Loop system tests, for the validation of the thrusters and new active tools, the CAN Bus network would "crash" when the control program is run, where no CAN bus signals can successfully be sent to and from the ROV. Coincidentally, a newer version of ModuleBase is implemented in the software. With so many variables at play, the testing was paused, and the teams began collecting data and noted down the situation. After analysing, it was determined that the software was the most likely point of failure, with individual module testing carried out to attempt to isolate the problem as identifying issues and bugs are easier with a small chunk of the program. The use of a version control software like GitHub allows programs to be easily reverted back to an older stable version. However running the program still resulted in the same problem. Final attempts in software testing was to use built-in linux CAN command line utilities, as those are heavily tested by developers, to directly send messages to devices connected to the CAN bus. When even this method failed to control the connected devices, the second most likely point of failure, determined to be the new fabricated tools, was to be investigated.

Bi-Electromagnet was independently tested next as it was a newly developed active tool, with the component level testing being done through a stand alone CAN bus tester. At the same time, other members in the team repeated the ROV system test by unplugging a single thruster each time. The results indicated that with 6 devices or less the ROV system remained stable, adding the 7th device would immediately cause stability issues, consequently proving that the problem was in the electronics system it was not a software issue. With this understanding, the team was able to narrow down the problem, identifying the need to look into more research about CAN bus electronics.

The answer was found in a forum post (cite) that mentioned the resistance of the CAN bus cannot be lower than the combined resistance of 60 ohm, commonly done with two 120 ohm termination resistors in parallel. With a multimeter, the resistance of the CAN bus network on our ROV was found to be only 16 ohm due to the addition of a termination in every device on the network. Consequently, new thruster electronics were made without the termination resistors and the resistance of the network is checked every time a new device is added to the ROV.

Prototyping and Testing

During the water tests, retrieving the ziploc bag was determined to be a challenging task as the downwash from the vertical thruster would carry the ziploc bag away due to its low weight. A thruster and ziploc bag is placed in a sink to test for the effect of thrust on the ziploc bag; it was determined that the tools cannot be near any thrusters.

The conclusion was that the ROV needs to approach the ziploc bag without using the vertical thrusters. Therefore we chose to design multiple prototype clamps to find the best solution, and use a water test to determine the best one.

First attempt of retrieving plastic debris includes a downward facing, two part gravity clamp. The clamp is held together by rubber band and grabs onto the ziploc bag by pushing down onto the PVC pipe until it latches on. However due to the vertical thruster being directly on top of the clamp, the pilot only has 1 attempt, as re-attempting will require the ROV to use the vertical thruster to move up, causing direct thrust to the ziploc bag, carrying it away.

A horizontal facing clamp that is designed to directly grab onto the ziploc bag was tested next. It only required the ROV to move forward when on the pool bed, thus not requiring the use of the vertical thruster for the task. However it too was proven to be unreliable as it required the plastic bag to be positioned vertically, this turned out to be unreliable as the bag was too flexible and unpredictable.

The chosen design for retrieving plastic debris, is the vertical clamp, held open by the electromagnet. It also does not require vertical thrust but is designed to grab onto the more predictable PVC pipe instead of the bag, making the most ideal design out of the three versions.

Safety

Safety Principles

At Fish Logic, safety is our number one priority. The safety of personnel, wildlife and environment is the prime priority of our team, and is considered for all operations and decisions carried out during the development of Hydron. To achieve this, Fish Logic has adopted the 4 phases of Emergency Management: Prevention, Protection, Response and Recovery. Prevention measures are taken to avoid potential hazards and accidents. Protection equipment is used when certain exposure to hazards cannot be avoided and can be controlled, such as wearing safety glasses and protective gloves when using a power drill or a sharp tool. Responses should be quick and effective should an unfortunate incident happen. Recovery of the work area back to safety standards after the incident will be a full analysis of how to prevent such problems. New team members are brief on the safety principles, and taught safety procedures required for both in the workshop and at the pool side. Vehicle safety features are considered right at the design stage to ensure the ROV meets all safety requirements.

Vehicle Safety Features(chart

Finance

To balance our finances, Fish Logic requested our mentor to write a proposal based on our budget to the FDCT, our main income source to apply for the funding. FDCT has provided Fish Logic with generous funding for our current project, the Hydron, as well as our previous projects. Our secondary source of income is from our school, Macau Anglican College, which sponsors our project as well as the travel expenses to our local pool.

The income is estimated approximately to the funding and is included into the budget plan. The budget is splitted into development of core system and mission specific tools, budget for travel expenses are also allocated once the amount of water trials are confirmed. As a company with limited income, the team must stick to the budgeted expenditures. Whenever receipts are collected, it is entered in the budget, a project costing sheet and is compared against the budget to make sure that the capital is used properly and no extra capital is used.

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 expenses of the last ROV. The income is estimated approximately to the funding and is included into the budget plan. Once the income has been received, the team verifies the amount meets our projected 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

School Name:	Macau Anglican College	**Reporting Period:**	From:	8/1/2019
Instructor:	Andy Tsui		To:	7/1/2021
Team Name:	Fish Logic			
Income				
Source				**Amount**
FDCT Grant				HKD 30,000.00
Macau Anglican College				HKD 10,000.00
Enpenses				
Category	**Type**	**Descrition/Examples**	**Projected Cost**	**Budgeted Value**
Hardware	Re-used	Blue Robotics thrusters	HKD (5,760.00)	HKD -
Hardware	Purchase	3D printer filament	HKD (4,000.00)	HKD (4,000.00)
Shipping	Purchase	To swimming pool	HKD (4,000.00)	HKD (4,000.00)
Hardware	Purchase	Blue Robotics thrusters	HKD (2,880.00)	HKD (2,880.00)
Hardware	Purchase	Waterproof plugs and general electrical components	HKD (2,000.00)	HKD (2,000.00)
Hardware	Purchase	Camera	HKD (2,000.00)	HKD (2,000.00)
Hardware	Purchase	Electronics	HKD (8,000.00)	HKD (8,000.00)
Hardware	Purchase	General hardware	HKD (3,000.00)	HKD (3,000.00)
Total Expenses				HKD (31,640.00)
Total Expenses -Re-used /Donations				HKD (25,880.00)
Total Fundrasing Needed				HKD (14,120.00)

Figure 32.Budget

School Name:	Macau Anglican College			**Reporting Period:**		From:	8/1/2019
Instructor:	Andy Tsui					To:	7/1/2021
Team Name:	Fish Logic						
Date	**Type**	**Category**	**Expense**	**Description**	**Sources/Notes**	**Amount**	**Running Balance**
11/27/2019	Purchased	Electronics	Optic Fibre	20m circular optic fibre and adapter		$ (300.00)	$ (300.00)
9/1/2019	Purchased	Electronics	CAN transceiver	Beetle CJMCU		$ (1,200.00)	$ (1,500.00)
9/1/2019	Purchased	Electronics	CAN transceiver	Beetle CAN PCB		$ (100.00)	$ (1,600.00)
11/27/2019	Purchased	Electronics	Tether			$ (1,200.00)	$ (2,800.00)
10/13/2019	Purchased	Hardware	Waterproof Plugs			$ (2,500.00)	$ (5,300.00)
1/10/2020	Purchased	Electronics	Motor Driver			$ (50.00)	$ (5,350.00)
1/10/2020	Purchased	Hardware	Electromagnets			$ (200.00)	$ (5,550.00)
1/10/2020	Purchased	Hardware	Camera board			$ (500.00)	$ (6,050.00)
4/30/2021	Purchased	Hardware	Magnets			$ (400.00)	$ (6,450.00)
9/1/2019	Purchased	Hardware	3D Print filament			$ (4,000.00)	$ (10,450.00)
6/3/2020	Purchased	Hardware	Carbon fiber tube			$ (200.00)	$ (10,650.00)
8/17/2019	Re-used	Hardware	Ring LED camera			$ (700.00)	$ (11,350.00)
9/1/2019	Purchased	Electronics	Raspberry Pi 4			$ (1,000.00)	$ (12,350.00)
7/3/2019	Cash Donated	Funds	-	Funds from Macau FDCT		$ 30,000.00	$ 17,650.00
12/25/2019	Purchased	Electronics	Step Down Converter	48V to 12V		$ (600.00)	$ 17,050.00
12/24/2019	Purchased	Hardware	Camera			$ (150.00)	$ 16,900.00
12/24/2019	Purchased	Hardware	Monitor			$ (900.00)	$ 16,000.00
8/17/2019	Re-used	Hardware	Power supply			$ (950.00)	$ 15,050.00
1/10/2020	Re-used	Hardware	Blue Robotics			$ (2,880.00)	$ 12,170.00
7/30/2020	Purchased	Hardware	Gamepad	Xbox controller		$ (1,600.00)	$ 10,570.00
9/1/2019	Re-used	Hardware	Anderson Powerpole			$ (400.00)	$ 10,170.00
9/2/2020	Purchased	Electronics	ESC			$ (1,000.00)	$ 9,170.00
9/1/2019	Purchased	Hardware	PU foam			$ (200.00)	$ 8,970.00
6/3/2019	Purchased	Others	Team Shirt			$ (1,440.00)	$ 7,530.00
3/13/2021	Cash Donated	Funds	-	Funds from Macau Anglican College		$ 10,000.00	$ 17,530.00
7/11/2021	Purchased	Shipping	-	To swimming pool		$ (5,000.00)	$ 12,530.00
Total Raised							$ 40,000.00
Total Spent							$ 27,470.00
Final Balance							$ 12,530.00

Figure 33.Project costing table. (All currency in HKD)

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 in the budget, a project costing sheet and is compared against the budget to make sure that the capital is used properly and no extra capital is used.

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