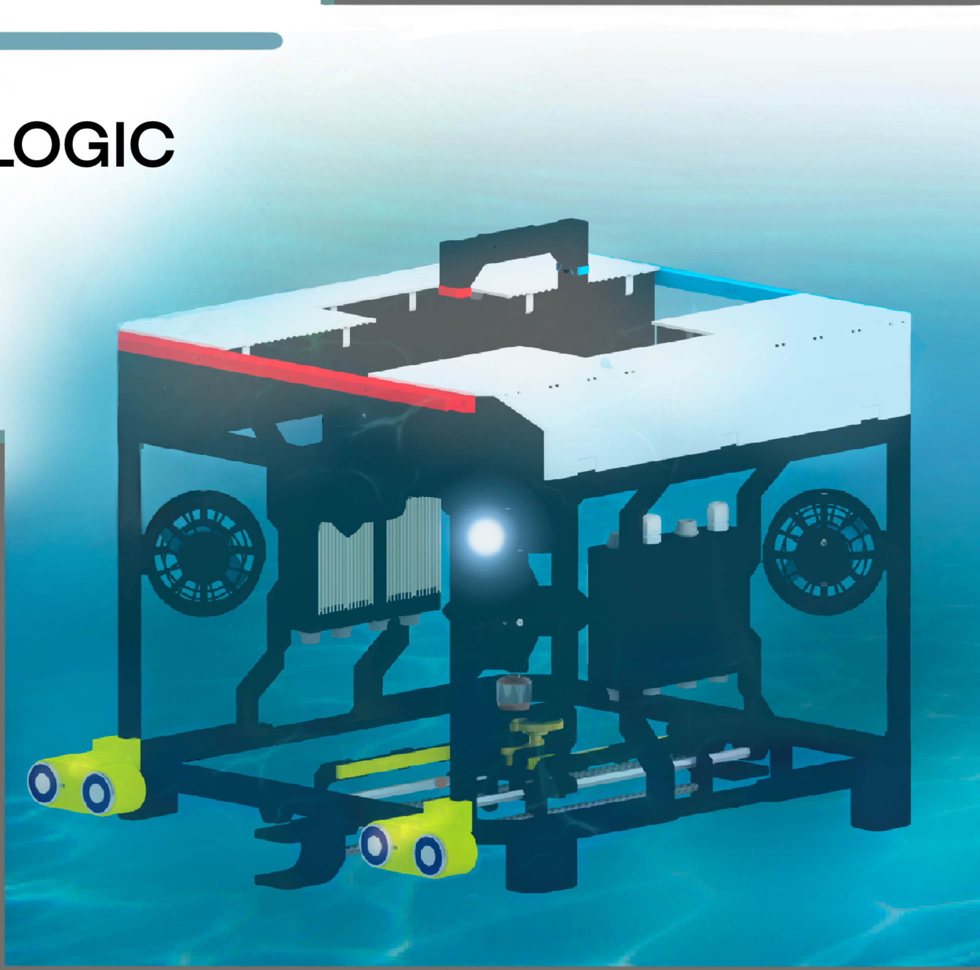
OTODUS

FISH LOGIC



Mentors
Mr Andy Tsui
Mr Ryan Ip

Members	Roles
Isaac Sin Wai Teng	CEO & CTO
Kimi Wong Wan Hei	COO & CFO
Kevin Sio Ka Wun	CMO
Hou Fong Chan	Head of Software
Ada Leong Weng Sam	Head of Fabrication
Chester Lo Ngou Hei	Prop Manager & Mechanical Engineer
Chloe Kwok Ka Kio	Head of Design & Senior Fabricator
Justin Ngo Ting Wei	Pilot
Julio Da Silva Nogueira Smith	Development Team Commander
Argus Hong Lat Hei	Development Team Pilot
Thomas Lei Chon Weng	Senior Mechanical Engineer
Charles Hung Kai Tai	Safety Officer & Mechanical Engineer
Ryan Chan Chon In	Mechanical Engineer
Edward Lei Kuok Lon	Mechanical Engineer
Daniel Lei Man Tat	Mechanical Engineer
Alison Wong Sin Iok	Mechanical Engineer
Isla Cheong In Wan	Mechanical Engineer
Yoanna Lei Un Lam	Fabricator
Stephanie Ma Wan Tong	Fabricator
Onching Lam	Graphics Designer

FISH LOGIC
MACAU ANGLICAN COLLEGE

Taipa, Macau SAR

聖公會中學(澳門)
Macau Anglican College

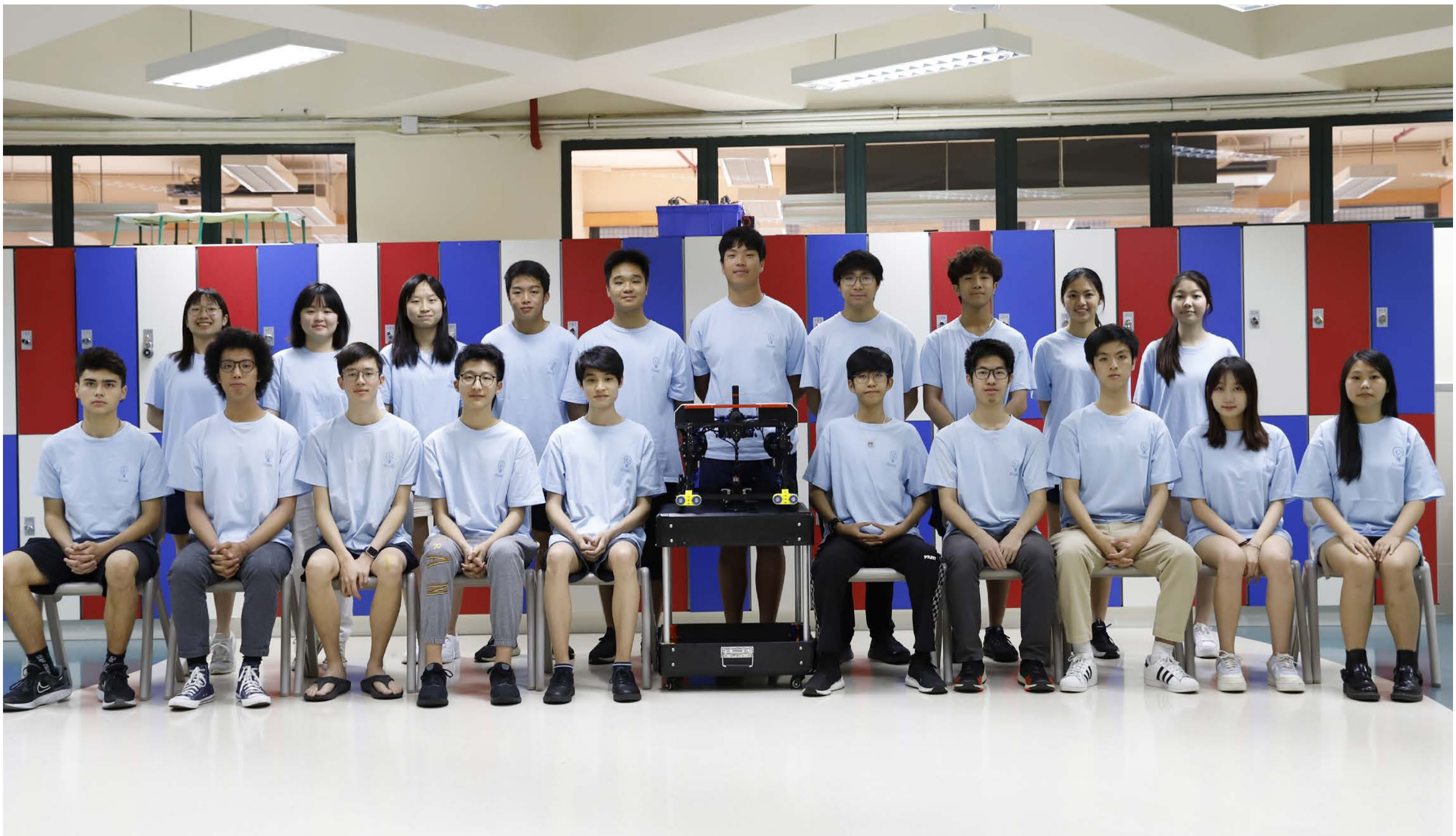
Abstract

Otodus is Fish Logic's sixth Remotely Operated Vehicle (ROV), designed on the request for proposals by MATE Center and our wider global community for an ROV to assist in marine renewable energy, offshore aquaculture and monitoring the impacts of climate change. To meet the desired functionalities, Fish Logic, a company dedicated to developing underwater ROVs, has designed Otodus with a flexible configuration. Otodus is capable of maintaining offshore wind turbines and fish aquaculture, deploying BGC Floats to monitor ocean conditions and finding the Endurance wreck.

Otodus is fully designed by the twelve dedicated members of Fish Logic. The design is an evolution of Fish Logic's previous ROV, Hydron, with the emphasis on prioritizing safety and functionality, followed by 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 Otodus'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". Otodus 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 the Otodus encompasses 1 year with about 6830 work hours. The market value of Otodus is 35958.17 HKD.



Members of Fish Logic (Photo By: Ryan Chan)
Front row: Julio, Hou Fong, Justin, Kevin, Isaac, Kimi, Thomas, Chester, Chloe, Ada
Back row: Alison, Isla, Onching, Edward, Ryan, Charles, Daniel, Argus, Stephine, Yoanna
(From left to right)

Table of Contents

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 year development period is divided up and plotted into a Release Planning Timeline. Its 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.[1]

To implement scrum, there are 4 types of documents known as artifacts: release planning, product backlog, sprint backlog and burn down chart.

Product Backlog, which is a priority list of deliverables that covers the entire scope of the project that the team needs to achieve for each sprint and the sprint backlog, a priority list developed at the start of each sprint of all the tasks to be completed in the current sprint. Previously, both lists were written in Notability. However, other team members were not able to contribute to the list/documents and progress reports were slow as they need to be manually created. This year Fish Logic adopted Jira, a proprietary agile management software, that allows team members to view

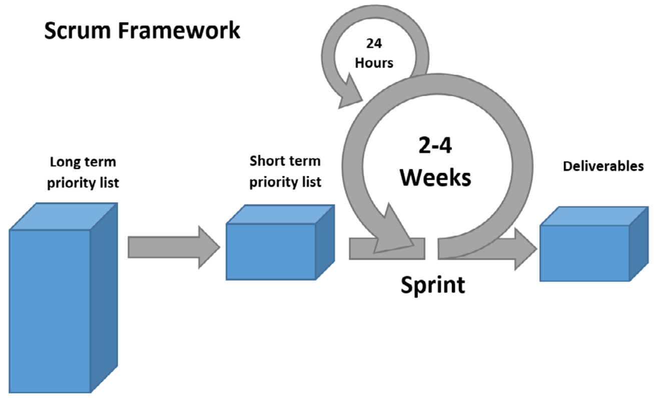


Figure 1. Scrum Framework

the current progress of the sprint, the backlog of tasks yet to be completed before the sprint ends, as well as access to update the progress of their tasks. Jira also automatically generates a burn down chart and cumulative flow diagram of all the deliverables, which shows the overall progress of the project. Our CEO, in this case referred to as the Scrum Master, selects tasks from the sprint backlog and briefs the team in a daily standup. Any obstacles to upcoming tasks are also discussed and 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 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 of promoting the transparency of resources to other potential users in the team, the

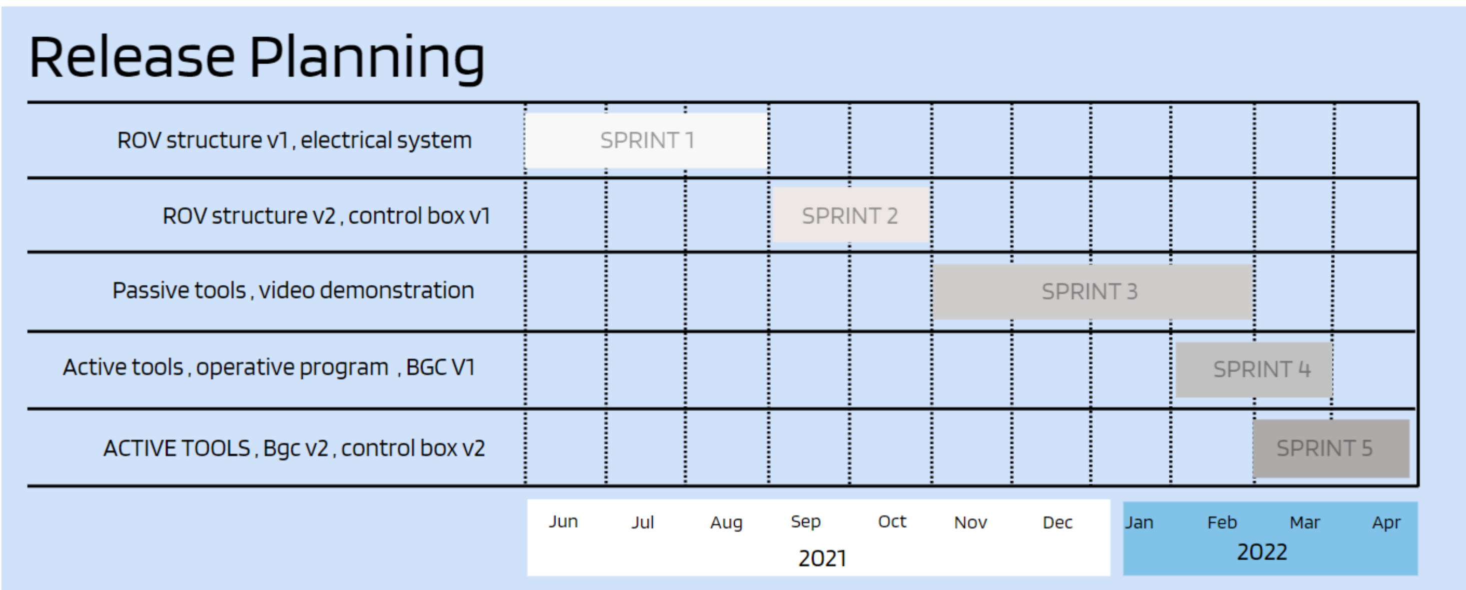


Figure 2 .Release Planning .

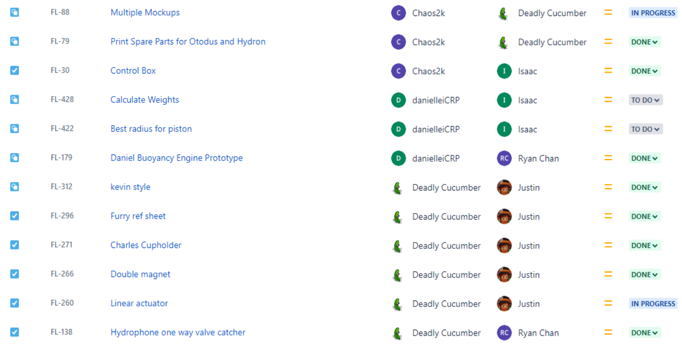


Figure 3. Product Backlog

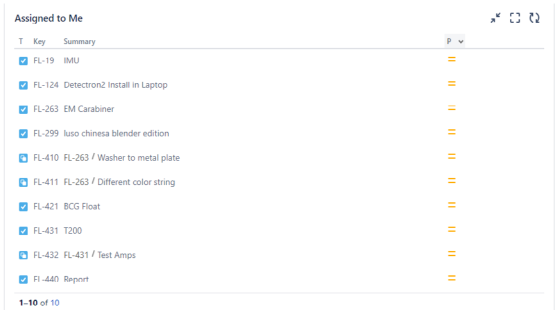


Figure 4. Sprint Backlog

Figure 5. Burn Down chart

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 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.

Design Rationale

Design Evolution

Fish Logic continues to use many of the features and design principles carried on from previous years, established ranging back from the ROVs: Leviathan (2017), Blazin' Hydra (2018), Electro Stargazer (2019) and Hydron (2021). 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 the 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, individualized control schemes, and custom set-ups based on pilot preference 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, passive design options are considered first, but active tools are chosen for tasks that require higher precision motion. The mounting of mechanical parts is standardized by the Standard Mounting System (SMS5), allowing any tools and payload with SMS5 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 CAN bus. CAN bwus 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 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 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.

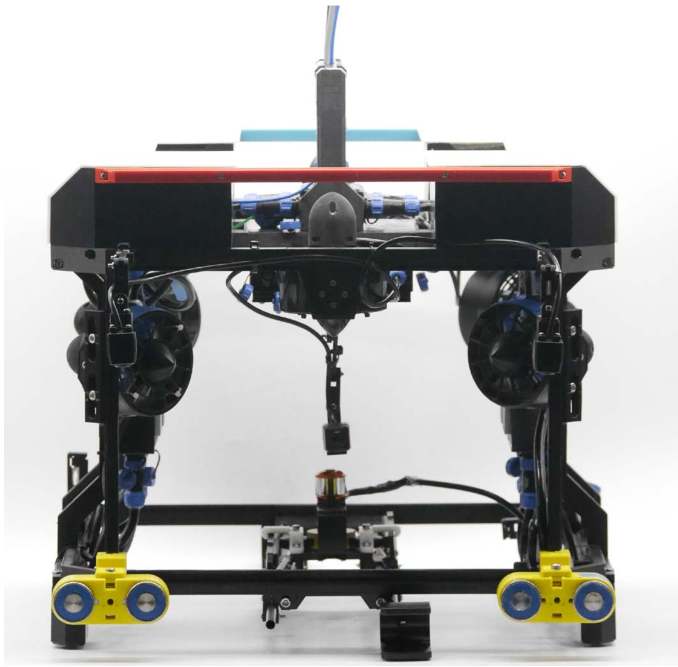


Figure 6. Photo of Otodus ROV

Previous years, our team has prioritized using passive tools over active tools due to their simplicity and reliability underwater. However, with the experience gained from previous years of competing, Fish Logic is able to design and build reliable active tools. Through applying our design philosophy by standardizing and modularizing active components such as ESC hubs and motors, it has reduced the time taken to design and build new active tools without compromising on reliability. Active tool is chosen over the passive alternative if the time taken to complete the task can be reduced.

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 programs designed in conjunction with each other and according to pilot preferences, optimizing the approach to each task while minimizing affecting 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.[2] 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.[3] 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 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. 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 the tool design is optimized for manufacturing.

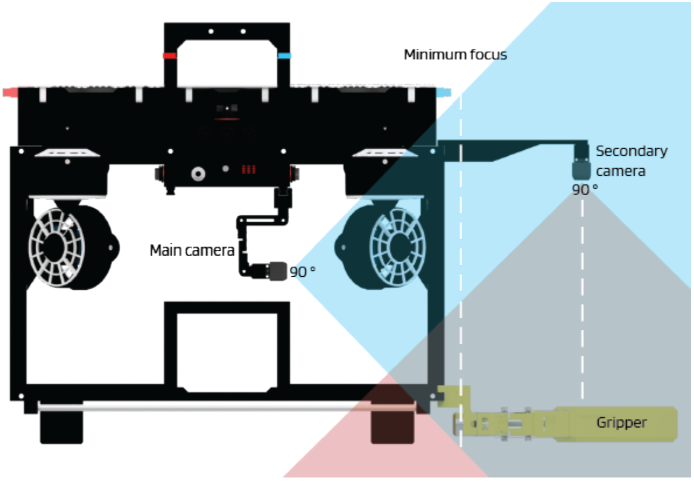


Figure 7 . Systematic Process for Tool Development.

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.

Innovation

Standard Mounting System 5

The Standard Mounting System 5 (SMS5) is Fish Logic's fifth generation 3D printed quick mounting system which is used for the attachment of tools and cameras to the Otodus ROV.

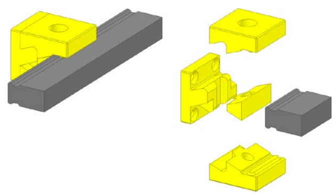


Figure 8. Standard Mounting System 5

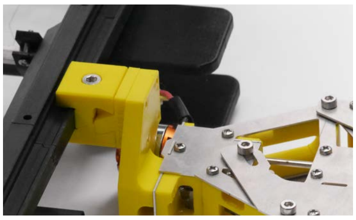


Figure 9. Gripper attached using SMS5

SMS5 consists of a detachable clamp and rail. Each SMS5 clamp can be secured onto a SMS rail using only a singlew M5 screw. All ROV tools are SMS5 compatible by incorporating the standardized centerpiece of the SMS5 clamp. Improving upon last year's SMS4, SMS5 increases durability by adding a center wedge component to the clamp which creates additional friction through one extra contact surface. This provides a more reliable clamping force that can account for a larger tolerance for SMS rails with dimensional inaccuracies or excessive wear. The rail is the counterpart of the clamp that allows any tools and camera with a SMS5 clamp to be placed in precise locations along the many SMS rails on the ROV. SMS rails all around the structure of the ROV 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 (2018), the SMS5 clamps are backwards compatible with SMS2, 3 and 4. Our standard SMS5 centerpieces are also reverse compatible with SMS4 clamp components. The SMS5 clamp has been tested to be capable of resisting movement of up to 343N in the direction of the length of the rail.

The Micro SMS5 (mSMS5) clamp is a smaller variant of SMS5 that is used for lighter loads such as cameras and cable clips. The mSMS5 clamp also incorporates the center wedge design that improves durability just like the larger SMS5. This smaller size also allows cameras to be mounted closer to the tools while being lighter and taking up less space on the ROV.

Figure 10. Camera attached using mSMS5

Synthetic Dataset

For all of the computer vision tasks, Fish Logic uses the Detectron2 object recognition algorithm which requires a large amount of training data. Our initial attempt to gather real world data indicated it is impractical to capture, manually segment and label enough images to be used for training data. It took roughly 1 hour just to take and label 100 images. Even by using data augmentation to increase the amount of data through adding slightly modified copies of already existing data, the result of the augmentation was less than ideal and even with augmentation, there is still not enough data. Models trained with those data were over-fitted, as other test objects were misinterpreted as the target object (false positives). Another issue is it is hard to simulate the lighting effect and hue of the water in a pool above water in a photo booth, which forces us to train an AI to be general. This is when our team discovered Zpy, a python library that is an integrated blender to automatically render, segment and label images.[4] As a result, our team took on the challenge to learn Blender to create photo realistic renders of the props in the underwater environments for the training of Detectron2. [5] To achieve a photorealistic render, 360° High Dynamic Range Images (HDRI) of the environment around our school inflatable pool and competition pool venue were captured to accurately recreate the lighting environment. Both the school inflatable pool and the swimming pool were recreated in Blender. Caustics were generated with ray-tracing to simulate the accurate lighting patterns produced by water waves. To automatically generate a large amount of training data, Zpy can be scripted to randomize the position of props and camera angles in every image. Zpy outputs the training images and annotations in COCO format, which can easily be used to train Detectron2. The output resolution and camera field of view is tuned to be the same with the AHD camera used on the ROV. The use of Blender with Zpy produced a sufficient amount of photorealistic and perfectly labeled data and new data could be generated whenever needed. This highly automated process also ultimately saved our team a lot of time, which was spent on improving the algorithm instead.

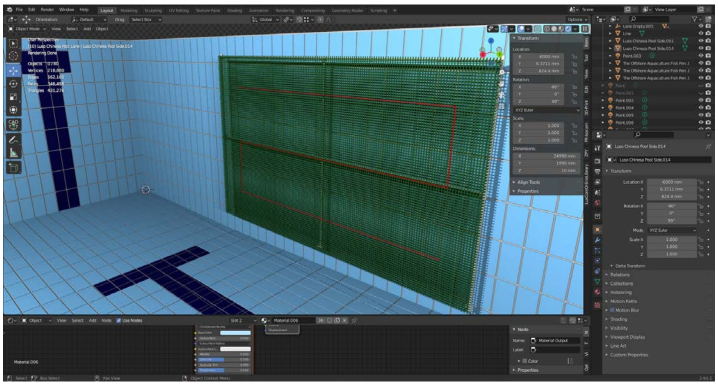


Figure 12. Render of Fish Pen in Blender

Simulator

Fish Logic over the years rarely had access to a pool to fully test the capabilities of the ROV. This bottlenecked 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.[6]

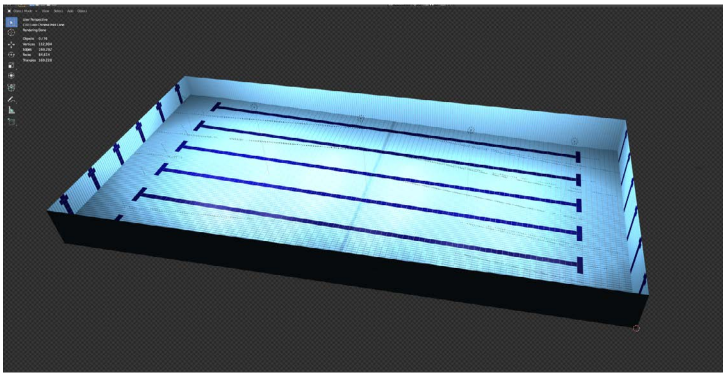


Figure 11. Render of the swimming pool using Blender

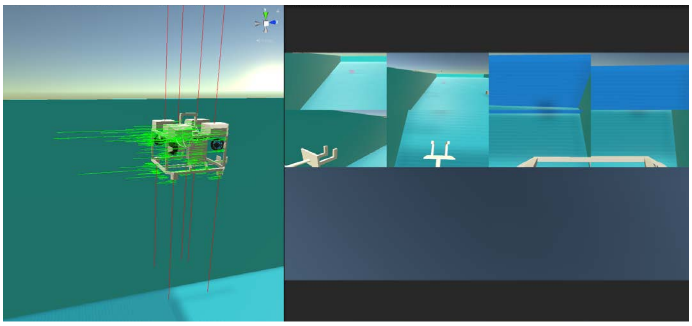


Figure 13. ROV Simulator in Unity

Mechanical

Propulsion and Vehicle Dynamics

Using the Fish Logic ROV simulator, the baseline requirements for the ROV were established 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 movement speed of 0.6 m/s in all directions.

A Vectored Thrust Configuration was chosen with 4 Blue Robotics T100 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 maximum speed of 0.63 m/s in all directions.

As the tools mounted on the bottom layer of the ROV changes between every water test, the center of mass of the ROV changes. Since any misalignment between the center of thrust with the center of gravity will produce a pitching motion to the ROV during every lateral acceleration, an adjustable slot was integrated into the ROV structure for the height of the thrusters to be adjusted. This aligns the thrusts of all lateral thrusters with the center of gravity of the ROV, eliminating unintended pitching motion during lateral maneuvering.

Vehicle Structure

The Otodus frame is a 3D printed structure made of PLA+, strengthened by 7mm aluminum hex rods. Since the SMS5 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 a 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 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 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 contact of external elements to potential hazards on the ROV. The adoption of integrating hollow aluminum hex rods within the 3D printed frame has allowed the frame to be much thinner, stronger and reduce hydrodynamic drag for faster acceleration. Individual parts of the Otodus 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.

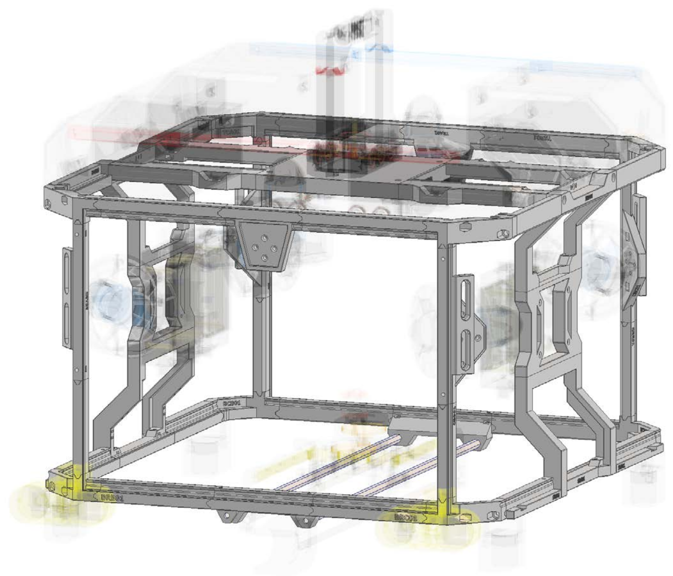


Figure 15. Otodus frame

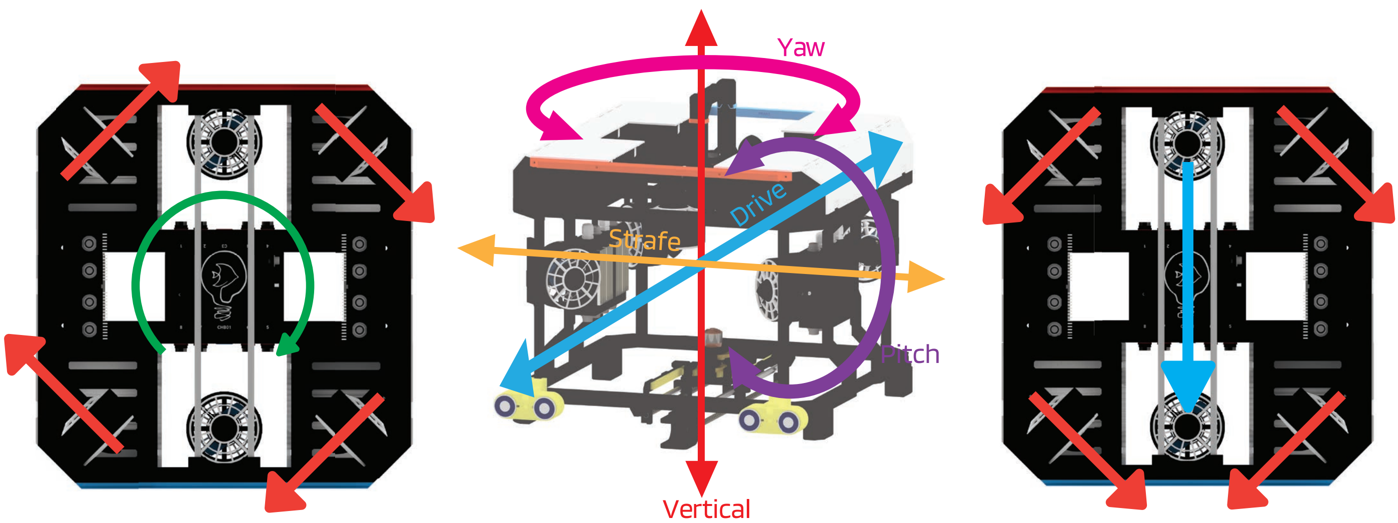


Figure 14. 5 Degrees-of-Freedom produced by 6 Thruster Configuration.png

Material Choice

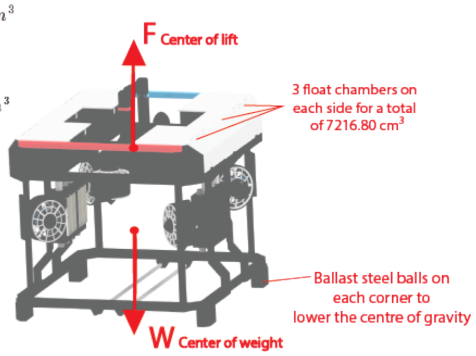
Materials and manufacturing methods are chosen to complement their use cases and the design of the components to be produced. 3D printing is chosen for its design flexibility. PLA+ from eSUN is the choice of material for all the fused filament fabrication (FFF) 3D printed parts on the Otodus. PLA+ is 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 it is a biodegradable thermoplastic which has less impact on the environment as it can be broken down by bacteria after it has served its purpose. For the Otodus ROV, aluminum 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 surfaces. MSLA is also used for a piston in the vertical profiling float as resin prints are impermeable to water and have the precision to house a watertight O-ring seal. Laser cut 1mm sheet aluminum is used in the structure of the gripper for its stiffness and strength. Steel plates that are laser cut are attached to tools that interact with electromagnets. (Refer to table 1 for details)

Buoyancy and Ballast

To ensure ease of use for the pilot, our aim for the buoyancy of the ROV is for it to stay upright and to maintain its depth. To achieve this, the overall density needs to be as close to the density of water as possible. High density PU (Polyurethane) foam is used to provide upforce to counteract the weight of the ROV in water by trapping air in its structure. The foam is cut into blocks of a few standard sizes, which can be fitted into any of the six foam chambers situated at the top corners of the ROV to provide a high center of buoyancy.

For an accurate measurement, our team uses the most direct and practical method: weighing the ROV in water using an electronic scale. To offset the ROV weight in water, the volume of float required to displace the amount of water to achieve neutral buoyancy is then calculated with the density of PU foam. The size of the foam chambers is designed to house enough volume of foam to offset the weight of the Otodus with additional capacity to account for extra payloads. Fine adjustment of buoyancy can be done swiftly by adding or removing standardized chunks of foam from the foam chamber via a flip-up lid that can be opened single-handed by pressing the magnetic button latch.

$$W = 44.5\ N$$
$$F_L = W \quad \textit{to achieve neutral buoyancy}$$
$$Volume\ of\ foam = \frac{Buoyancy}{Foam\ density \times Gravitational\ field\ strength}$$
$$Buoyancy = 44.5\ N$$
$$Density = 77.82\ kg/m^3$$
$$Gravitational\ field\ strength = 9.81\ m/s^2$$
$$Volume\ of\ foam\ required\ to\ achieve\ neutral\ buoyancy = 4918.99\ cm^3$$



$$Total\ float\ chamber\ capacity - Volume\ of\ foam = Extra\ volume$$
$$7216.80\ cm^3 - 4918.99\ cm^3 = 2297.81\ cm^3$$
$$2297.81\ cm^3\ \ Extra\ volume\ of\ foam\ to\ account\ for\ ROV\ payload$$

Figure 16. Weight and Bouyancy Diagram with Calculations

25mm stainless steel ballast balls (64g each, 0.55N weight in water) are added to the bottom of the ROV in each corner. This lowers its center of gravity while additionally supporting it when 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 achieves the above criteria.

Power Distribution

The Otodus 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.

Materials	PLA	PLA+	SLA Resin	Aluminum	Steel
Density(g/cm³)	1.24	1.24	1.18	2.7	7.84
Elongation at break (%)	5	29	6.2	3	15
UTS (MPa)	37	60	91	90	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. Manufacturing techniques and materials table [7][8]

Electrical system

SID

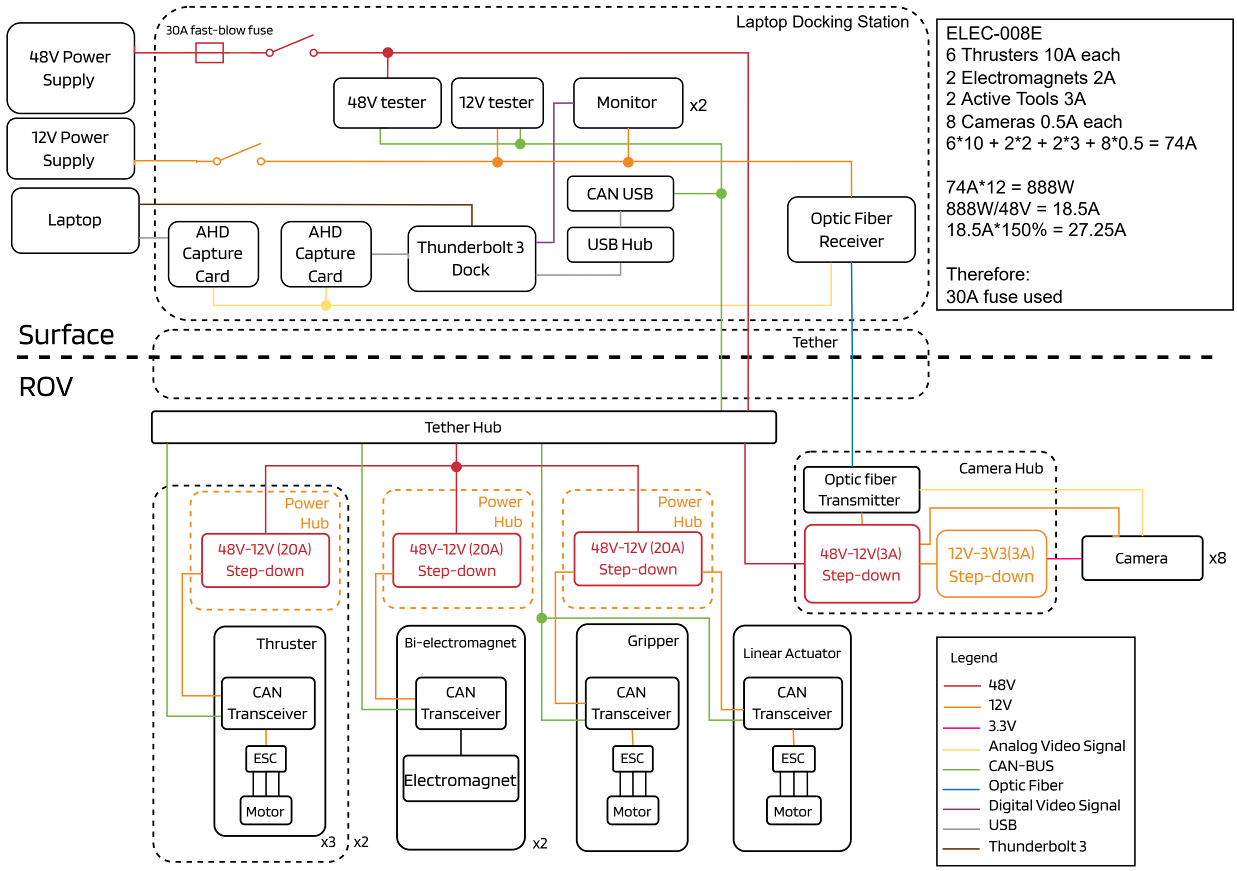


Figure 18. SID

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 using 2 screws, a replacement can be swapped quickly in the unfortunate circumstance of a Power Hub failure.

Tether

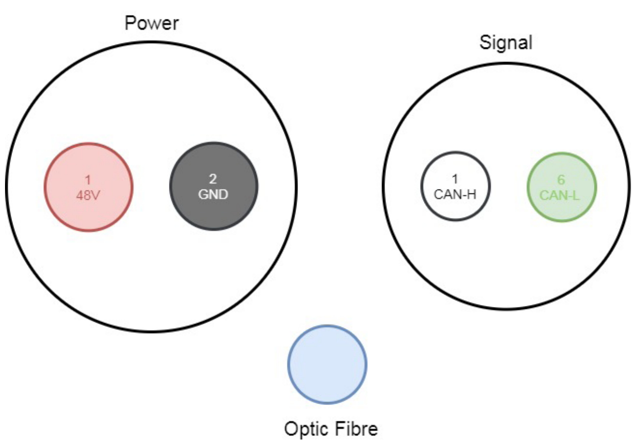


Figure 17. Tether cross section

The power tether uses a pair of 4mm² RVV cables rated for 22A.[10] 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[11] cable which are shielded twist 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).

Our team has considered the use of a single neutral buoyant tether with 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 tether clamp 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.

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. Keep workplace clean and organized for a safe and harzard 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.

Connectors

The connectors on the Otodus 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 mismatched connection, 7 pin Weipu SP13 connectors are solely used for 48V components, while cameras use 4 pin Weipu connectors. Since each pin is only rated 5A current, 2 pairs of pins are used for power and ground to allow for manipulators and thrusters to get sufficient current. Although the connectors claim to be waterproof, the back of the connectors are filled with epoxy and silicone grease is used between the pins and socket as a further measure to prevent water leaking into the connector.

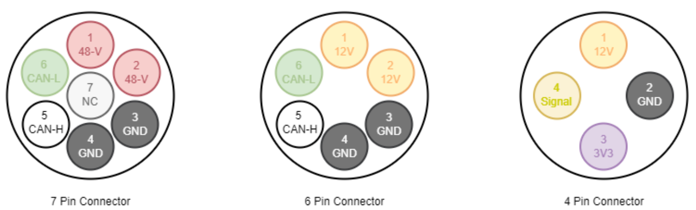


Figure 19. Universal Connectors

Camera System

The Otodus 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 remaining 6 cameras act as secondary cameras which are mounted on the SMS rails on the ROV to provide extra viewing angles for mission specific tasks. The use of Analog High Definition (AHD) cameras were due to their 720p resolution instead of 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 camera hub for signal and power.

Figure 20. AHD Camera

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 receivers convert 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. Nvidia Encoder (NVENC) codec is used to decode camera signals. These signals are then sent to the 2 monitors through the Thunderbolt-3 Hub to provide the pilot with 4 different camera views on each monitor through Open Broadcasting Software (OBS).

Control System

CAN Bus System

CAN (Controller Area Network) is the messaging protocol used in the Otodus that allows onboard components to communicate to each other within the same bus network. Along with the Universal Connectors, CAN bus is the key to achieving standardization. It allows any CAN bus device to connect to any sockets along the bus network. It also enables hot swapping, allowing Otodus' configuration to be flexible, modular and simplifies its circuitry and assembly. This contributes to the ease of maintenance as well as enabling future upgrades and expansion of the system.

CAN bus was designed originally 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 that makes it an ideal communication protocol for the length of tether used in the Otodus (20m). 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 Otodus 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 Otodus' CAN bus network spans across the tether all the way 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 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.

CAN Bus Software Protocol

The requirement for our CAN bus network for our ROV is to be able to communicate with up to 20 nodes (connected devices). The 11-bit identifier of the messaging frame (Figure 21) is utilized to specify the level of broadcast. The first level is the node level, where the messages are specific for one node, which 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 make sure all nodes are responsive, as well as request for the onboard temperature and voltage readings from all nodes. Table 2 shows a complete chart of ID to specify levels of broadcast among various classes of devices. After the ID comes the data, it 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.

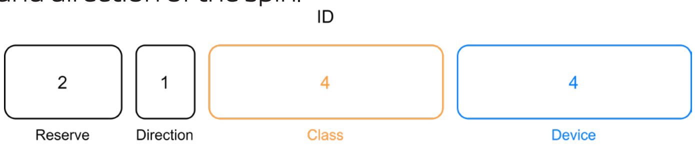


Figure 21. CAN bus Messaging Frame

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

Table 2. CAN bus ID Structure.pdf

As messages are being broadcasted along the whole network, bus contention occurs when two or more CAN controllers start initializing messages at the same time, which may cause thruster movements to stutter, or even stop transmitting messages completely. CAN bus resolves this conflict by having every node that wants to transmit monitor the bus, and compare their IDs to see who has the more dominant bit (0) and the less recessive bit (1), to which the dominant transmitter wins the arbitration. This action is performed on the whole CAN bus network until 1 transmitter is left, while other potential transmitters wait until the bus is free. Thrusters are prioritized for more smoothness in control, resulting in the thruster IDs set to have more dominant bits (0). Messages that are sent back from nodes, such as temperature and voltage data, should be less prioritized compared to the messages sent to nodes.[12]

CAN Bus Thruster

The Otodus uses Blue Robotics T100 and T200 thrusters, for their powerful yet compact design. With the use of a CAN bus network, Fish Logic decided to integrate CAN bus electronics onto the thruster. The Beetle is the chosen microprocessor for its small profile, no larger than the width of 4cm. A built-in ATMEGA was chosen because it is a popular microcontroller featured in arduino. A printed circuit board (PCB) is 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, while remaining small enough to fit inside the enclosure.[13]

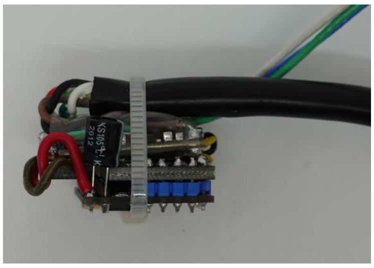


Figure 22. CAN electronics and ESC

To maintain the streamlined and compact design of the thruster, the electronics housing is designed to matched 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 a small layer height for 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. Dshot is the chosen protocol as being a digital protocol, it removes the need to do ESC calibration compared to analog protocols such as PWM (Pulse Width Modulation), as PWM relies on length of pulse to determine the value, where different speeds in the oscillator of the microcontroller and ESC may affect the value 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.

Control Program

The ROV control program written in Python consists of independent, loosely coupled modules, each serving a specific purpose. Communication between modules is performed by the PyPubSub library so that modules can broadcast messages while subscribing to specific topics. Python is a synchronous language by nature. However, since many different modules need to run together for the ROV to function, the Python library Threading is used to run modules in parallel.

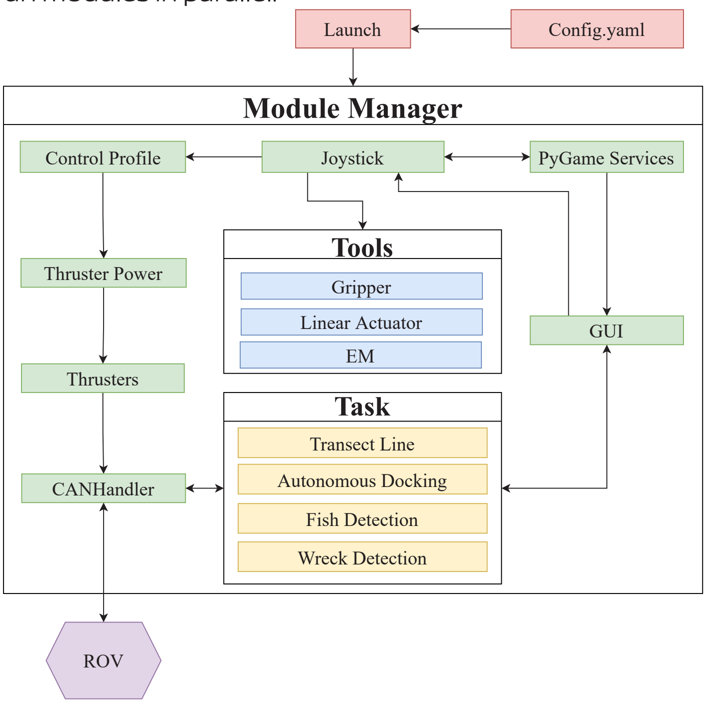


Figure 24. Module Diagram of Otodus Control Program

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

Table 3. Functions of Modules in the Control Program

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.

Thruster Power 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.[14]

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.

$$\mathbf{B} = \begin{pmatrix} D_{FL} & D_{FR} & D_{BL} & D_{BR} & D_{UF} & D_{UB} \\ S_{FL} & S_{FR} & S_{BL} & S_{BR} & S_{UF} & S_{UB} \\ Y_{FL} & Y_{FR} & Y_{BL} & Y_{BR} & Y_{UF} & Y_{UB} \\ V_{FL} & V_{FR} & V_{BL} & V_{BR} & V_{UF} & V_{UB} \\ P_{FL} & P_{FR} & P_{BL} & P_{BR} & P_{UF} & P_{UB} \\ R_{FL} & R_{FR} & R_{BL} & R_{BR} & R_{UF} & R_{UB} \end{pmatrix}$$

key:

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

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

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

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.

Graphical User Interface (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 be done with printed text or a graphical indicator.

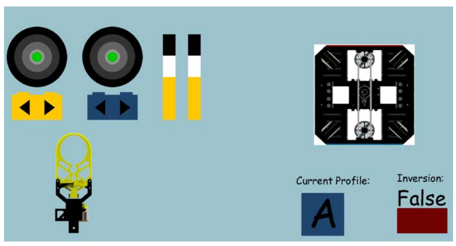


Figure 23. GUI of the Control Program

Status bars are used to display the thrust values of each thruster. Gripper movement animations 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.

Control Box


Figure 25. The Otodus Control Box

The Otodus Control Box contains two 24-inch 1440p monitors that allows the pilot to see all 8 cameras in their native resolutions. Below the monitors is the Laptop Docking Station that provides all the power and signal ports for the ROV and links up with the ROV control laptop via two USB Type-C cables.

FlatPack Laptop Docking Station


Figure 26. FlatPack Laptop Docking Station

The FlatPack Laptop Docking Station contains an optic fiber receiver, 2 AHD capture cards, a Thunderbolt 3 hub, a CAN-USB and a USB 3.0 hub. The CAN-USB is used to receive and transmit CAN bus signals to the ROV to allow commands such as maneuvers to be executed. A tester for 12V and 48V electronics is available on the FlatPack to conduct tests on electrical parts quickly and easily. With power routed through the FlatPack, the built-in kill switch allows the power of the ROV to be completely cut off in an emergency. No AC power was used in the FlatPack and Control Box.

Mission Specifics

Gripper V2


Figure 27. Gripper V2

The Gripper V2 is Fish Logic's second generation double-pivot claw that is designed as a general purpose tool with specialized grip surfaces for the transportation of the hydrophone, removal of marine growth, collection of morts and placement of seagrass.

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 acts as a power screw by transferring the rotational motion into a linear motion that articulates the jaw. The double pivot claw configuration was chosen as it is relatively mechanically simplier compared to the linear and adaptive gripper prototypes that the team has tested, without compromising its capability in accomplishing its designated tasks.

The Gripper claw is divided into sections where each surface serves a different purpose. The front of the claw is shaped like jagged teeth for the transportation of the hydrophone, the removal of marine growth and the collection of the mort. The large semi-circular surfaces are for retrieving circular objects, and the smaller round surface is specifically for the transportation of seagrass. Various sections of the gripper can be repurposed to pick up dropped objects as needed during the mission.

The opening and closing speed of the Gripper is adjustable up to 70°/s and can hold onto objects well exceeding the weight of 25N, which is the heaviest object the Gripper needs to handle.

Bi-Electromagnet


Figure 28. Bi-Electromagnet

The Bi-Electromagnet (BEM) is a general purpose tool used in retrieving the inter array cable, attaching buoyancy modules, placing hydrophone and transporting the BGC.

The choice to use electromagnets was due to its simple working principle with no moving parts making it easy 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. Otodus, equipped with two BEMs, 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 patch for the fish pen in order to ensure a secure contact. The two electromagnets on the BEM are rated for a combined force of attraction of 36kg. LEDs are embedded into the BEM to indicate the status of the individual EMs.

An onboard H-bridge motor driver allows polarity of the electromagnet to 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. Multiple mounting points are located around the BEM, which allows tools such as the BEM clasp to be mounted on it.

After initial water trials, our team found that having the BEM pitching up at an angle of 30° allowed the patch to better hook onto the fish pen net. The hinge is designed with notches that limit the tilt angle of the BEM to find the exact adjustment angle easily.

Task 1

BEM Latch Attachment

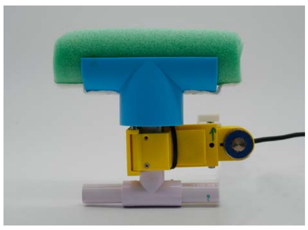


Figure 29. Buoyancy module held with BEM latch

This latch is an attachment to the BEM for the placement of the new buoyancy module as well as the deployment of the hydrophone base. The flap that swivels on a hinge has a metal plate which allows it to be attracted to one of the electromagnets to form a latch. Foam brackets are installed on both the core and the flap to provide a firm grip on the new buoyancy module and the base of the hydrophone. The Latch is released by turning off the BEM, letting the flap swing open, allowing the buoyancy module or the hydrophone to be deployed.

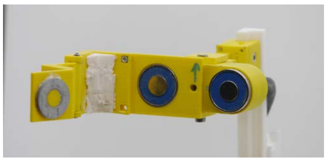


Figure 30. Opened BEM Latch

Hydrophone Holder

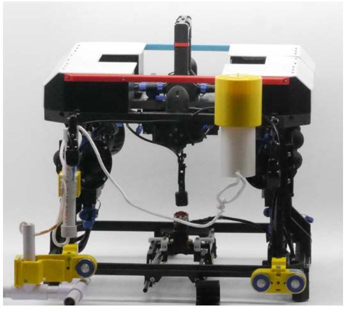


Figure 31. Hydrophone Holder on ROV

While the hydrophone can be held with just the BEM Latch, the hydrophone would float around, blocking the camera's view and tangling with the other tools on the ROV during deployment. The Hydrophone Holder keeps the hydrophone in place by using a simple U-shaped bracket with foam that prevents the hydrophone from slipping during transportation. The Float Cap takes advantage of the buoyant property of the hydrophone float; this cylindrical tool with a hollow end keeps the float in place until the ROV deploys the hydrophone.

Hydrophone Retriever

After 5 minutes of deploying the hydrophone, this cup-shaped Hydrophone Retriever retrieves the hydrophone with the front opening that allows the rope between the hydrophone and the float to slide in. After the rope enters the Retriever, the ROV would ascend and the float would be trapped within the cup. There are funnel-shaped guides on both the top and side openings to help guide the rope into the Retriever, thus improving consistency and speed in completing the retrieval.

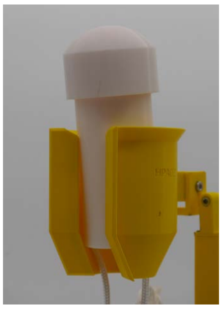


Figure 32. Hydrophone Retriever

Inter-Array Cable Carabiner

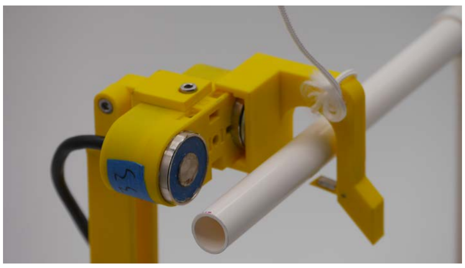


Figure 33. Inter-Array Cable Carabiner

The Inter-Array Cable Carabiner is used to remove the damaged section of the inter array cable. A U-Shaped trap with repelling magnet flaps is designed to latch on the PVC pipe of the cable.The carabiner attracts to the BEM through a ferrous metal plate. Once attached to the cable, the pilot may detach the tool from the BEM, allowing the cable to be retrieved to the surface by pulling a cable attached to the carabiner.

Cable Installer

Mounted at the bottom of the ROV is the cable installer, it is used to deploy and secure the new power cable quickly and precisely. The pilot aligns and places the new power cable into the cradle using a downwards facing camera. Once the cable is lined up on both ends, the cable installer extends outwards, pushing the wet mateable connectors to attach onto the neighboring cabling. In the cable installer, the brushless motor in the center drives a metal gear train, resulting in a gear reduction of 2:49. This gear train spurs two mirrored linear gears, which are attached to carbon fiber rods pushers for the connectors. Once the connectors are secured, the cable installer retracts the pushers back into the ROV frame. During this backward motion, small plates mounted on the carbon fiber rods unfasten two spring loaded cable clamps, thus releasing the cable from the ROV onto the cradles.

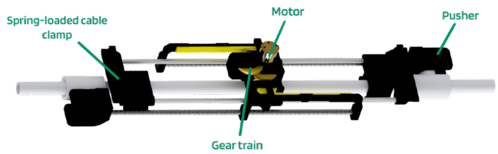


Figure 34. Render of the Cable Installer

Buoyancy Module Carabiner

The Buoyancy Module Carabiner is used to remove the failed buoyancy module. It is mounted onto the bottom rail of Otodus. The Carabiner consist of 2 Y-shaped traps with repelling magnetic flaps designed to latch onto the tee-shaped handle of the buoyancy module. The tool latches onto the buoyancy module by pushing upwards until both flaps rebound, trapping the handle in the tool. The ROV then rotates the buoyancy module 180 degrees by pulling backwards and upwards carefully before detaching the buoyancy module away from the cable. The Y-shape allows the handle to slip inside the trap easily.

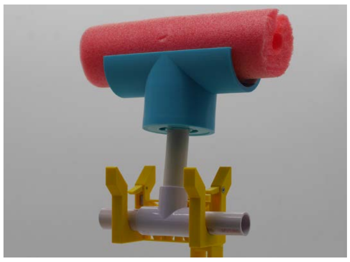


Figure 35. Buoyancy Module Carabiner

Pin Retrieval Magnet

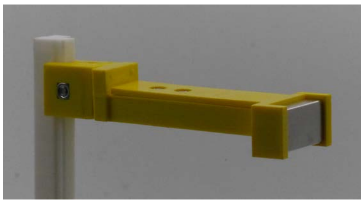


Figure 36. Pin Retrieval Magnet

This magnetic tool exploits the ferrous properties of the pins on the ghost net and inter-array cradles. The magnet used is a 40x20x10mm N35 Grade neodymium magnet. It is protected by a 3D printed casing integrated with adjustable extenders and SMS5 clamps, which allows it to be mounted on any of the rails on the ROV.

Task 2

Object Recognition

Detectron2 is the machine learning model used for object recognition tasks: differentiating mort from live fish, identifying the fish pen for autonomous line following and identifying the red button for autonomous docking. Detectron2 is an open source library developed by Facebook AI Research that provides object detection and segmentation algorithms. Detectron2 was chosen over our previous use of You Only Look Once version 5 (YOLOv5) as it can perform instance segmentation which increases the accuracy of the model by learning the differences between the object and background.[15] Although Detectron2 requires more computing power, since the laptop used for ROV control has a RTX 3060 graphics card, it has enough graphics computational performance to handle Detectron2 without affecting camera decoding and ROV control.

To train Detectron2, each object known as a class that we need to detect requires training, validation and testing datasets. In each dataset, for each original image, there is an image of the object mask and annotations of the object saved in a json file. The model is trained on the training dataset until the mean percentage accuracy is the same across training and validation data to prevent overfitting. When training is completed, the model is used on the testing dataset to ensure the trained model can confidently(add data points if easy) detect new images that it has not seen before.

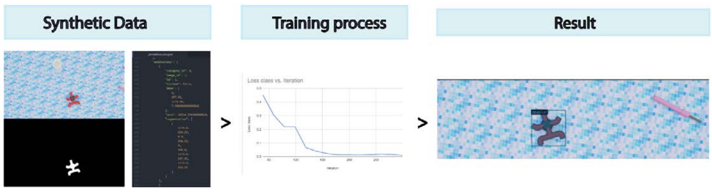


Figure 37. Training Detectron2 with Synthetic Data

Autonomous Inspection of Transect Line

To autonomously follow the transect line, Detectron2 is first used to identify the rope on the transect line by segmenting it out. As the ROV is more hydrodynamically stable along the drive and vertical axis, a camera mounted on the side of the ROV is used to detect the rope, thus the algorithm only needs to focus on movement on a single plane that is parallel to the fish pen. Through detecting the starting knot of the rope, the ROV is first moved forward. A negative feedback loop is used to ensure the rope is in the middle of the camera view, once a corner is detected the ROV moves down, this is repeated until the end of the rope is detected which indicates the end of the transect line. By taking advantage of the ROV being hydrodynamically stable, the scope of the autonomous program is reduced, thus saving development time of the program.

Seagrass Hook

This 3D printed Hook is used to collect seagrass. The width of the tool is made to the width of the arch of the seagrass with some tolerance for the pilot to retrieve it easily. It is mounted on the bottom rail of the ROV and the height of the tool is that of the seagrass so that it can slip under and retrieve it. It was made as light as possible by hollowing out the tool to reduce material used.

Figure 38.Seagrass Hook

Fish and Wreck Length Detection

The Length Detection Program measures the length of both the wreck and fishes. It is programmed in Python and utilizes the pygame library. For fish length detection, a side facing photo of each live fish is captured. Since the height is the same across all the fishes and is a known quantity, they can be used as a reference point to estimate the length of the fishes. The program displays the captured image of the fishes one by one to let the user click the reference points and the points which the distance between is to be detected. The process is repeated with all 3 fishes, and the average length of the fish is returned. Additional information such as number of fishes and constants from species and environment is entered in the program to calculate the biomass of the fish using the following formula:

Figure 39. Fish and Wreck Length Detection Program

$$Mass = (Number\ of\ Fish)^{*}(a)^{*}(Average\ Length^{b})$$

Task 3

GO-BGC resurface calculator

This custom calculator program is used to plot the surface location of the GO-BGC float on the grid map. Using the GO-BGC's current speed, direction and the time until the next surface event as input, the program outputs a marker on the grid map, plotting the next surface location within the exact square on the grid map.

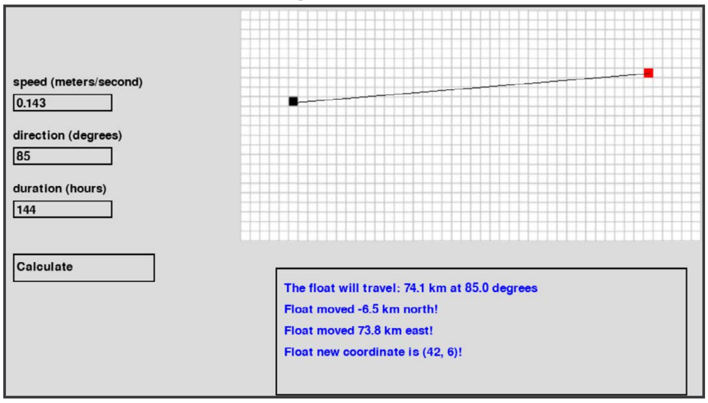


Figure 40. GO-BGC Resurface Calculator

GO-BGC Carabiner

This is a downwards facing carabiner that is mounted on the front rail of the ROV to catch the floating GO-BGC. By positioning the Carabiner inside the loop of the GO-BGC float, the ROV retrieves the float by descending, with this Carabiner pulling the bottom of the loop downward. This opens the magnetic flap and traps the loop inside the Carabiner. The Carabiner will remain closed as the magnet from inside the Carabiner and the magnetic flap repel each other.

Figure 41. Go-BGC Carabiner

SeaLift Vertical Profiling Float

The SeaLift is Fish Logic's vertical profiling float that is designed to complete 2 vertical profiles of a 2m deep pool within 2 minutes. The mechanism of the buoyancy engine of the SeaLift consists of a piston that draws and pushes water to an external flexible bladder. The piston with 2 O-rings spans across the inner diameter of the canister turning the whole canister into a syringe, this maximizes the movement of the piston into changes in internal volume. The piston is actuated by a power screw where a DC Motor drives a threaded rod, then a threaded block turns the rotational motion into linear motion. Limiting switches at both ends of the mechanism constrains the maximum and minimum travel.

Figure 42. The SeaLift Vertical Profiling Float

To guarantee the piston to be waterproof, resin SLA printing was utilized. SLA printing also has the precision to ensure the watertight seal of the 2 O-rings while not being too tight, where the friction is greater than the motor driving force.

When the float reaches the surface, a magnet attached to foam descends in a tube to activate a hall effect sensor inside the canister to indicate the surface has been reached. On the other hand, when the float reaches the bottom, a magnet on a guided rod hits the bottom of the pool and moves up to activate the bottom hall effect sensor. All electronics are powered with 8 AA batteries in series to provide 12V. The Beetle CJMCU microcontroller is used to process the sensor data and control the motor driver for the piston, and the USB interface of the Beetle is wired to an external 4 pin female socket to allow the Beetle to be reprogrammed.

The SeaLift is transported to the designated area by the ROV using the BEM before it is deployed. Weights are mounted on the bottom to make sure the SeaLift is neutrally buoyant when the piston is at the central position.

Autonomously creating the photomosaic

As the ROV flies over the transect line, each time the ROV passes a row of rectangular sections, a top view image of every rectangular section in the row is captured and placed in corresponding order of the photomosaic on the GUI. After collecting the images of all four rows of rectangular sections, the program stitches all eight images together to display a photomosaic of the transect line.

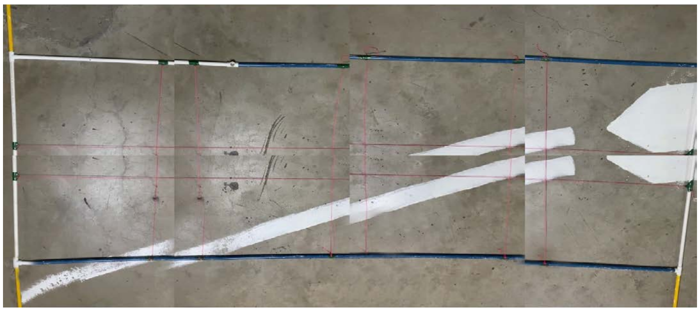


Figure 43. Autonomously Creating the Photomosaic

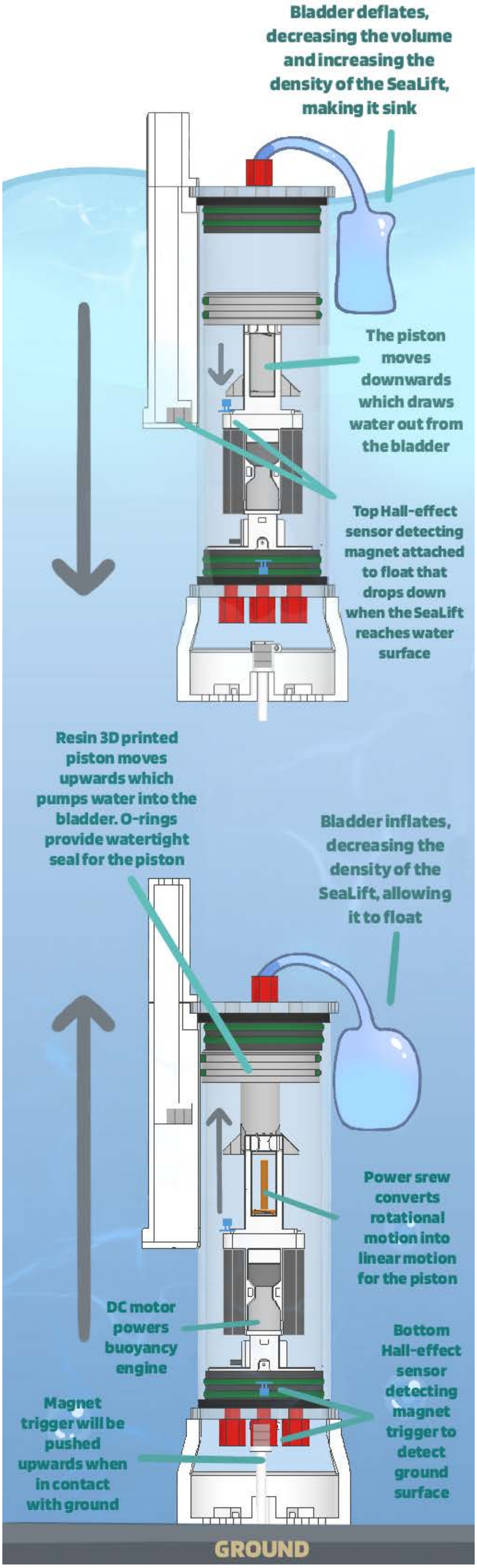


Figure 44. Motion of the SeaLift at the surface and bottom

Mission program

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 the difficulty and tool combination to have 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 make sure all tools are well integrated together without compromising the functions of each other. The final mission program requires 2 resurfaces, thus 3 layouts where all tasks can be completed in the 15 minute time limit.

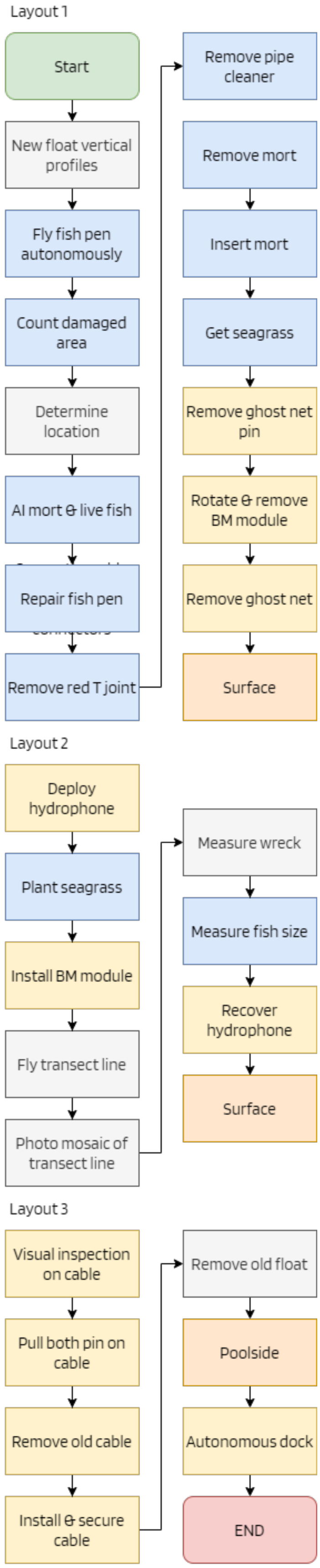


Figure 45. Mission Program of Otodus

Legend

Task 1	Task 2	Task 3

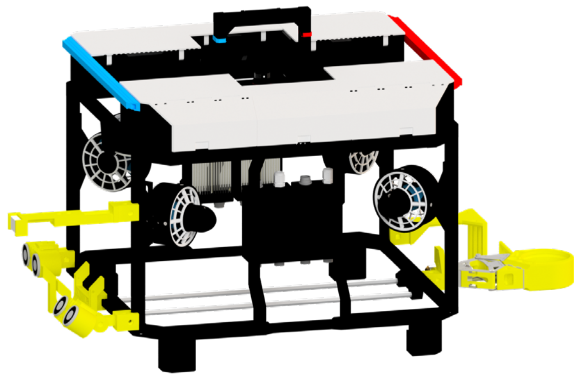


Figure 46. Otodus Layout 1

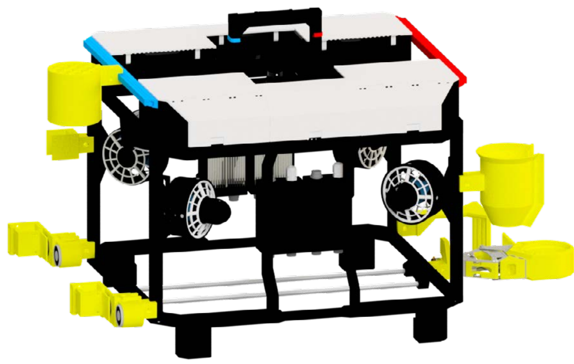


Figure 47. Otodus Layout 2

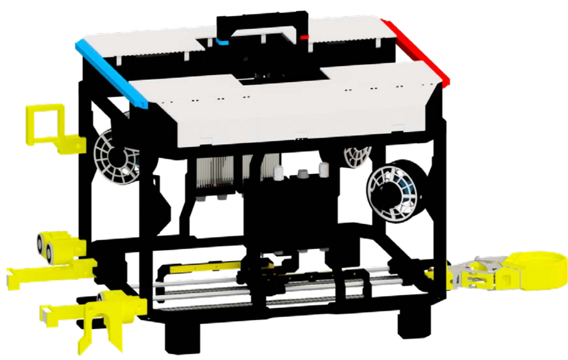


Figure 48. Otodus Layout 3

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 considers 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 fulfill the required specification are compared to the resources and skills required to fabricate it in-house. The features, performance, cost and especially reliability of the parts are extensively evaluated before purchase. When no suitable parts are available, 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 was 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 Reused 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 year was a small evolution upon the success of last year's Hydron. Since the basic platform of the Otodus only had minor improvements over the Hydron, thus the core electronics are in common with Hydron and therefore reused. This maintains the commonality between platforms and has the added benefit of using Hydron as our stable testing platform. The Control Box is a reused empty power tool box from our workshop that happened to be a perfect fit of our monitors and allowed us to save costs from needing to purchase a custom box.

Testing and Troubleshooting

Vehicle 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 processes become more formal as the system matures. Tests are categorized into development, qualification and acceptance tests. Development tests are used to determine hardware capability in excess of requirements and to find weaknesses, such as the 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 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 the SeaLift was the best example of the rapid design-build-test cycle used by Fish Logic. The conceptual prototype of the SeaLift vertical profiling float was first built using readily and commercially available materials to quickly test the mechanism and understand more about the system. The design used 2 syringes housed inside a large 110mm diameter canister that draws a combined volume of 80ml water from 2 medical blood bags as external bladders. Prototype electronics consisting of AA battery holders, a DC motor and a BeetleCJMCU microcontroller were quickly put together. Both syringes are driven by the DC motor through a power screw that moves the syringe plunger. Each sub-system goes through a Qualification test before assembly, such as testing the power screw mechanism with a bench power supply. The electrical system is tested with a multimeter after everything is soldered. Water seal tests are conducted to make sure the canister and connections are waterproof up to 2 meters. After qualification of every sub-system, the whole vertical float is fully assembled and tested in a large bucket filled with water. Finally the conceptual prototype is brought to a local lake to be field tested. The onboard program only consisted of the core functions that cycled through drawing and pushing fluid to the bladder. However, due to a bug in the program, the motor kept spinning after the syringe was fully drawn. As a result, the motor drew too much current and fried the motor driver. Luckily, spare motor drivers allowed us to continue testing, but this proved an active system that limits the movement of the syringe was needed. The tests showed the speed of the float descending and ascending only achieved 0.022 m/s and took 6 mins to complete 2 profiles. By considering the operation program as a whole and with a possible retry of the vertical profiles during the product demonstration, the current speed of float sinking and floating is considered too slow; hence the minimum speed is determined to be set to 0.044 m/s (3 minutes for 2 complete profiles).

Adding in more syringes to the existing float is not an efficient way to increase the volume change of the float, therefore, our team has decided to build a second iteration with the concept of directly changing the internal volume of the float by a moving piston. By essentially turning the canister itself to a giant syringe, a small change in the height of the piston can change the internal volume by a lot, allowing for the use of a smaller canister. To isolate and test the new concept, the second functional prototype was made without an external bladder to cut development time. This iteration had more consideration taken into the integration of the internal electronics for ease of maintenance. Magnets that activate hall effect sensors were added to detect when the float reaches the surface and bottom. Limiting switches are also added to the power screw as a way for the float to detect if the piston is fully extended or fully retracted. The second iteration of the float was successfully tested in a 2 meter deep swimming pool; the speed of float sinking and floating achieved the speed of 0.067 m/s and was able to complete 2 profiles under 2 minutes, exceeding our requirements. Thus, all systems work as intended.

The final SeaLift design is a merge of the previous 2 prototypes where the piston from the functional prototype is used to draw and push water from the bladder of the conceptual prototype. A cage is also designed to house the bladder and protect the bladder from punctures. Building 3 prototypes in rapid design-build-test cycles has allowed the team to achieve a better design sooner, instead of over-emphasising on planning on executing our first design solution in high detail that would have not delivered our required performance.

Troubleshooting Strategy

In the previous iteration, the Gripper V1, was fully 3D printed with plastic that had a tendency to lock up upon closing or opening to its maximum. While pilot training avoided this issue, our team was determined to eliminate this problem through a redesign.

At first it was thought to be a torque issue. To test this, a hand drill which had 60% more torque was connected directly to the driving shaft. However, even with the hand

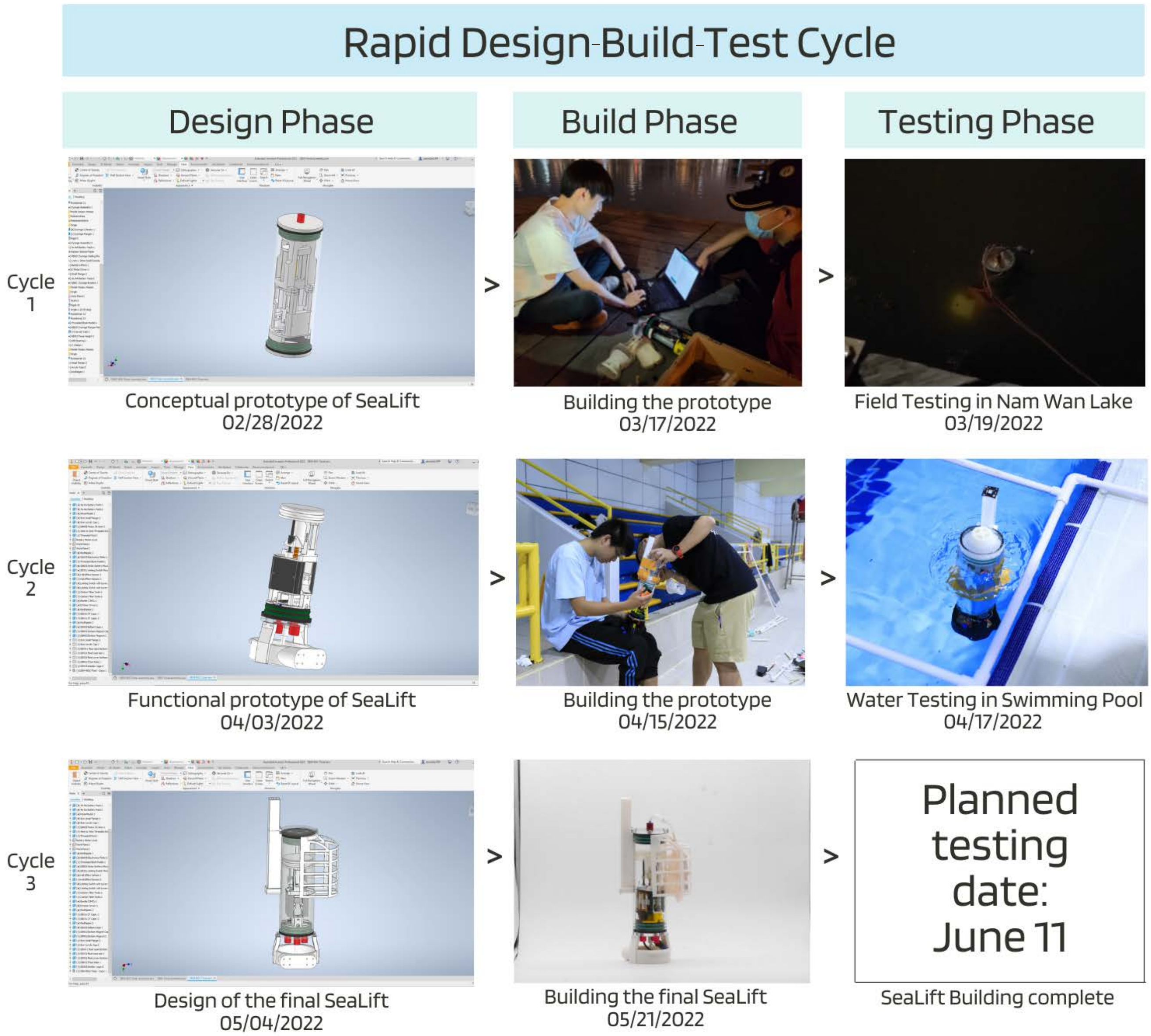


Figure 49. SeaLift Rapid Design-Build-Test Cycles

drill the gripper lockups persisted, as the static friction caused by a motor at its peak torque with rotational inertia digging the threaded block into the end stop is always higher than the force generated by the same motor from a standstill.

Another hypothesis was that the threaded block velocity was too high when reaching the end stop. A solution was tested by placing a spring between the the threaded block and end stop to reduce velocity before contact, enough to reduce tightening. This was not effective either, as the problem of locking persisted.

With ideas running out, a more scientific approach was sought by researching the phenomenon. Through literature review, the principles behind the power screw were finally understood. The force diagram of the power screw mechanism showed that the more flexible the system is, the more elastic deformation occurs when the threaded block hits the end stop. This deformation wedges the threaded block in, as the pressure exerted on the threaded block increases due to elastic deformation presents as higher friction when the threaded block is leaving the end stop. Based on this understanding, a single variable test which isolated the power screw mechanism was designed, which was made to be stiffer and with tighter tolerances. As hypothesized, no lockups were observed.

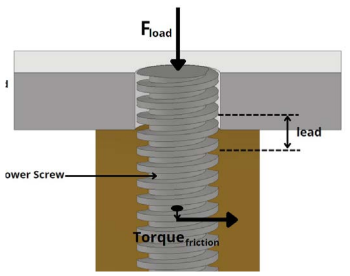


Figure 51. Rendered Mechanism of Threaded Block stuck at End Stop

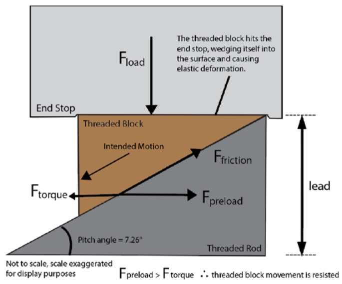


Figure 50. Force Diagram of Threaded Block stuck at End Stop

After some deliberation regarding CNC and other manufacturing techniques, the new gripper is a combination of a plastic structure with interlocking laser cut sheet aluminum integrated to minimize flexing. Tighter tolerances, metal gears and extra bearings were also used to reduce play in all moving parts. As a result, no more locking has been observed, furthermore, the reduction in bending is certain to increase the longevity of the gripper as a whole.

Through this experience, our team realized that a proper troubleshooting strategy based on scientific concepts and proper testing is still the ideal way of problem solving processes as it would have saved time from trying improper inconclusive experiments.

Safety

Safety Principles

At Fish Logic, safety is our number one priority. The safety of personnel, wildlife and environment is considered for all operations and decisions carried out during the development of Otodus. 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 is considered as returning the work area back to safety standards after an incident will be a full analysis of how to prevent such problems. New team members are briefed on the safety principles, and taught safety procedures required for both the workshop and pool side. Vehicle safety features are considered right at the design stage to ensure the ROV meets all safety requirements.

Vehicle Safety Features

To ensure the safety of the vehicle, the team personnel working around it, and the surrounding environment, several safety measures are taken as shown in the following table.

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 thruster shrouds are 3D printed and 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 by one or more hands.
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 on the control box to cut all power to the ROV in case of 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.

Table 4. Vehicle Safety Feature Chart

Finance

To balance our finances, Fish Logic requested our mentor to write a proposal to apply for funds based on our planned budget to the Macau Science and Technology Development Fund (FDCT), our main income source for the funding. FDCT is a foundation that provides funds to education, research and project development with the aims of technology development in the Macau SAR. FDCT has provided Fish Logic with generous funding for our current project, the Otodus, 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 shipping expenses to our local pool.

School Name:	Macau Anglican College	Reporting Period:	From:	01/09/2021
Instructor:	Andy Tsui		To:	25/05/2022
Team Name:	Fish Logic			
Income				
Source				Amount
FDCT Grant				40,000.00 HKD
Macau Anglican College				5,000.00 HKD
Expenses				
Category:	Type:	Description/Examples:	Projected Cost	Budgeted Value
Hardware	Re-used	Blue Robotics Thrusters	6,302.55 HKD	0.00 HKD
Electronics	Re-used	Camera	752.64 HKD	0.00 HKD
Hardware	Re-used	Re-Used Hardware	5,287.97 HKD	5,500.00 HKD
Electronics	Re-used	Re-Used Electronics	3,381.48 HKD	4,200.00 HKD
Hardware	Purchased	3D Printer Filament & Resin	1,399.44 HKD	1,500.00 HKD
Hardware	Purchased	Waterproof Plugs and Enclosures	827.85 HKD	500.00 HKD
Hardware	Purchased	General Hardware	13,616.60 HKD	15,000.00 HKD
Electronics	Purchased	Electronics	2,930.71 HKD	3,000.00 HKD
Transport	Purchased	To Swimming Pool	1,458.93 HKD	1,500.00 HKD
Total Expenses:				35,958.17 HKD
Total Expenses - Re-used/Donations:				20,233.53 HKD
Total Fundraisng needed:				15,724.64 HKD

Table 5. Budget Planning Table (All currency in HKD)

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 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 extra capital is used.

With the competition venue changed due to the switch to a telepresence competition, the team had a surplus in the travel budget as it is no longer possible to travel to the in-person competition venue. For shipping cost to the local pool, Fish Logic evaluated different trucking services and chose based on the criteria of cost, service, reputation and punctuality. Once the truck service was selected, the shipping budget was allocated based on shipping costs and the number of pool access dates.

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. All spending is tracked 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. During the development of the gripper, the production cost was also considered aside from functionality and weight issues. Due to this, instead of using CNC to produce the entire gripper, laser cut aluminum sheets were choose only for load bearing parts, not only for their lightness but also the lower cost. Other non-load bearing parts of the gripper were 3D printed to save on cost. 3D printing also allows us to accurately predict production costs as material consumption and printer running costs can easily be calculated before prints are made.

By incorperating finance planning with Scrum project managemet, 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		Reporting Period:	From:	01/09/2021
Instructor:		Andy Tsui			To:	25/05/2022
Team Name:		Fish Logic				
Date:	Type:	Category	Description:	Amount:	Expense:	Running Balance:
01/09/2021	Cash-Donated	Funds	Fund from FDCT	-	40,000.00 HKD	40,000.00 HKD
01/09/2021	Cash-Donated	Funds	Funds from Macau Anglican College	-	5,000.00 HKD	45,000.00 HKD
01/09/2021	Re-used	Electronics	720p AHD Camera	8	752.64 HKD	44,247.36 HKD
01/09/2021	Re-used	Electronics	Tether	1	1,200.00 HKD	43,047.36 HKD
01/09/2021	Re-used	Electronics	CAN transceiver (Beetle CJMCU)	8	282.24 HKD	42,765.12 HKD
01/09/2021	Re-used	Electronics	CAN transceiver (Beetle CAN PCB)	8	47.04 HKD	42,718.08 HKD
01/09/2021	Re-used	Electronics	Optic Fibre	1	70.56 HKD	42,647.52 HKD
01/09/2021	Re-used	Electronics	Motor Driver	2	11.76 HKD	42,635.76 HKD
01/09/2021	Re-used	Electronics	Step Down Converter (48V to 12V)	5	970.20 HKD	41,665.56 HKD
01/09/2021	Re-used	Electronics	ESC	8	799.68 HKD	40,865.88 HKD
01/09/2021	Re-used	Hardware	Blue Robotics Thruster	6	6,302.55 HKD	34,563.33 HKD
01/09/2021	Re-used	Hardware	Power Supply	1	950.00 HKD	33,613.33 HKD
01/09/2021	Re-used	Hardware	Gamepad (X-box Controller)	1	1,600.00 HKD	32,013.33 HKD
01/09/2021	Re-used	Hardware	Anderson Powerpole	1	400.00 HKD	31,613.33 HKD
01/09/2021	Re-used	Hardware	PU foam	-	200.00 HKD	31,413.33 HKD
01/09/2021	Re-used	Hardware	Optic Fibre Receiver and Transmitter	1 set	823.20 HKD	30,590.13 HKD
01/09/2021	Re-used	Hardware	AHD capture Card	2	1,173.65 HKD	29,416.48 HKD
01/09/2021	Re-used	Hardware	Electromagnets	4	141.12 HKD	29,275.36 HKD
21/3/2022	Purchased	Electronics	Thuderbolt 3 Hub	1	822.02 HKD	28,453.34 HKD
21/3/2022	Purchased	Electronics	24 inch Monitor	2	1,573.48 HKD	26,879.86 HKD
21/3/2022	Purchased	Electronics	Laptop docking Station Cables	10	415.84 HKD	26,464.02 HKD
6/2/2022	Purchased	Electronics	BGC Electronics	1 set	119.37 HKD	26,344.65 HKD
1/9/2022	Purchased	Hardware	Waterproof Plugs	56	503.27 HKD	25,841.38 HKD
1/9/2022	Purchased	Hardware	3D printer Filament & Resin	-	1,399.44 HKD	24,441.94 HKD
21/3/2022	Purchased	Hardware	Laptop	1	13,616.60 HKD	10,825.34 HKD
6/2/2022	Purchased	Hardware	Canister, Flanges & Endcaps	1 set	324.58 HKD	10,500.76 HKD
-	Purchased	Transport	To swimming Pool	-	1,458.93 HKD	9,041.83 HKD
Total Raised:						45,000.00 HKD
Total Spent:						35,958.17 HKD
Final Balance:						9,041.83 HKD

Table 6. Project Costing Table (All currency in HKD)

Acknowledgements

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

Macau Science and Technology Development Fund (FDCT) – Our sponsor for their generous donation of funding.

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. Andy – Our mentor for guiding our team and teaching us all about computer science.

Mr. Ryan – Our lab assistant at MAC for assisting us in experiments and purchasing.

Ryan Chan – For volunteering to teach mechanical design and project management.

Ryan Chan – Our mentor for giving advice in mechanical design and project management

Fish Logic Alumni: Gavin, Cerys, Joshua and Yorky for their help and advice

Autodesk – For free student license software.

Our Families – For their continued support and encouragement.

References

[1] "Agile Project Management." What Is Agile Project Management? | APM Methodology & Definition. Accessed April 10, 2021. https://www.apm.org.uk/resources/find-a-resource/agile-project-management/.

[2] Berg, Cliff. "SpaceX's Use of Agile Methods." Medium. Medium, December 9, 2019. https://cliffberg.medium.com/spacexs-use-of-agile-methods-c63042178a33.

[3] Gemert, Dennis Van. "Systems Engineering the Project." Project Management Institute, October 29, 2013. https://www.pmi.org/learning/library/systems-engineering-project-5857.

[4] H., Ponte, Ponte N., and Crowder S. "ZumoLabs/Zpy: Synthetic Data for Computer Vision. an Open Source Toolkit Using Blender and Python." GitHub. ZumoLabs. Accessed May 24, 2022. https://github.com/ZumoLabs/zpy.

[5] Wu, Yuxin, Alexander Kirillov, Francisco Massa, Wan-Yen Lo, and Ross Girshick. "Facebookresearch/Detectron2: Detectron2 Is a Platform for Object Detection, Segmentation and Other Visual Recognition Tasks." GitHub. Facebook Research, November 16, 2021. https://github.com/facebookresearch/detectron2.

[6] Vu, Ricky, and Paul Hodgson. "Unity Underwater ROV Simulator." ResearchGate, May 2021. https://www.researchgate.net/publication/351747090_Unity_Underwater_ROV_Simulator.

[7] "Esun Pla+ Filament Black - 1,75 Mm - 1 Kg." Creedo3D. Feed the Printer AB , May 4, 2022. https://www.creedo3d.se/en/product/esun-pla-filament-svart-175-mm-1-kg/.

[8] "The Mechanical Properties of Aluminum." Italpres. Dexanet. Accessed May 24, 2022. https://www.italpres.com/aluminium-die-casting-news/mechanical-properties-aluminum.

[9] Ashok, Reema. "Why Is the Center of Buoyancy below the Center of Gravity?" Quora, 2018. https://www.quora.com/Why-is-the-center-of-buoyancy-below-the-center-of-gravity.

[10] "The Full Name of RVV Cable Is Light Copper Core Polyvinyl Chloride Insulated Polyvinyl Chloride Sheathed Flexible Cable." https://www.wenchangcable.com/. Dongguan Wenchang Electronic Co., Ltd, June 2, 2021. https://www.wenchangcable.com/news/the-full-name-of-rvv-cable-is-light-copper-core-polyvinyl-chloride-insulated-polyvinyl-chloride-sheathed-flexible-cable.

[11] "Shielded High Voltage Flexible Power Cable TRVVP Cable Track Cables 6x0.5mm." ADAMICU. Accessed May 24, 2022. https://www.adamicu.com/en/h-pd-368.html.

[12] Administrator. "Arduino MCP2515 CAN Bus Interface Tutorial - CAN Protocol." Electronics Hub, October 6, 2019. https://www.electronicshub.org/arduino-mcp2515-can-bus-tutorial/.

[13] Sin, Isaac, and Paul Hodgson. "Integrating CAN Bus to Blue Robotics Thruster by Custom PCB and Protocol." ResearchGate, May 2021. https://www.researchgate.net/publication/351747085_Integrating_CAN_Bus_to_Blue_Robotics_Thruster_by_custom_PCB_and_protocol.

[14] Higgins, Brian. "Least Squares Solution and PseudoInverse." BGHiggins/UCDavis/ECH256/Jan_2012, January 2012. https://www.researchgate.net/file.PostFileLoader.html?id=559bb98a614325a5948b45ef&assetKey=AS%3A273808471068683%401442292434670 .

[15] Shashank, Sai. "Detectron2 Vs. Yolov5 (Which One Suits Your Use Case Better?)." Medium. iReadRx, August 3, 2021. https://medium.com/ireadrx/detectron2-vs-yolov5-which-one-suits-your-use-case-better-d959a3d4bdf#:~:text=Conclusion,dataset%20while%20YOLOv5%20ignored%20them.

Appendix: Safety Procedures

Workshop safety Checklist

General

- [ ] Safety equipment including safety glasses and protective gloves must be worn for using powertools and sharp tools
- [ ] Respirator must be worn when in contact with fineparticles
- [ ] Clear work area to prevent hazards (knocking things over, tripping hazard, etc.)
- [ ] Sufficient amount of tools and equipment
- [ ] Tools and equipment are properly stored
- [ ] Minimizing and maintaining least possible socialgrouping
- [ ] Masks are worn at all times
- [ ] 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 deck

- [ ] 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
- [ ] Thrusters are properly shielded
- [ ] No exposed copper or bare wires
- [ ] Screws and nuts are tight
- [ ] 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