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Olin College Aquaculture Profiler

Abstract

There has been a rise in demand for fish products in the US, leading to the need for more offshore aquaculture farms. These farms have been a source of controversy for many years. While some point to them as sustainable alternatives to land farms, there has been an outcry that aquaculture is bad for the oceanic ecosystem. Despite these arguments, not enough data exist to support either claim, particularly as to how damaging aquaculture is to the underwater environment. In response to this, we are developing a deployable, autonomous aquaculture profiler. The profiler is designed to be handled by two people, and can dive to varied depths, collect data, and return to the surface along a mooring line. It shows promise as a solution to the controversy surrounding fish farms, as it can help in data collection concerning the environmental impact. Additionally, it can act to monitor fish health on established aquaculture sites for more general use.

Introduction

Fish farms received a burst of initial support, as they were thought to not produce greenhouse gases and considered better for the environment. However, in recent years, several negative effects have come to light. Fishers complain that contamination from fish farms has led to depletion of the wild fish they catch (Martinez-Porchas et al.). In the case of shrimp farming, it is estimated that for every one million shrimp, four million other living organism are killed after getting caught up in netting (Martinez-Porchas et al.). Another of the major concerns is the eutrophication and nitrification of water.

On the other hand, seafood produced by saltwater fish farms accounts for 15 to 20 percent of the world population’s food consumption and provides important nutritional benefits to people in developing countries (Martinez-Porchas et al.).

Fish farms are fast becoming a vital component of the food industry but have many negative impacts on the environment. Ideally, we would want to develop a sustainable, eco-friendly aquaculture industry. To do this it is necessary to have the ability to take accurate measurements of their environmental impact. A proposed partial solution to this is an aquaculture profiler, designed for use on caged offshore fish farms. The scale of the project envisaged a medium-small underwater robot, able to be handled by two people, that can be deployed along a vertical mooring line to travel up and down a water column and collect data. The data can then be used to quantitatively measure waste and other impacts, as well as to monitor fish health for more routine use on the fish farm. For example, nitrite and nitrate concentrations produced by fish waste can be accurately measured, as well as dissolved oxygen levels. Ocean beds can be examined for bleaching and inhabitability by other sea creatures such as lobsters. Netting can be examined for entrapped marine life.

The Olin College Aquaculture Profiler is three summers in the making and is currently manifested as a physical prototype capable of deployment and autonomous data collection. This report goes over decisions made in the design process, the profiler’s physical design, and goals for autonomy, as well as the results of its testing.

Methods

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The premise for the profiler is that it should be capable of traversing up and down a vertical mooring line, hover at specific depths, take data measurements, and return to the surface autonomously. For the sake of easy recovery should the robot lose power, it must be slightly positively buoyant and release its braking hold on the mooring line (if braking is engaged) when power is cut off. A depth sensor must be integrated. A frame of some sort for handling and robustness is vital, as are rope guides which can easily be opened and closed for attachment of the profiler to a guide rope.

The strongest profile for durability and resistance to water pressure are spheres. Cylinders have similar structural integrity and are more applicable in this context, as they are better suited for holding contents and being repeatedly opened and closed. For this reason, all waterproofing chambers are cylinders. Batteries, electronics, and sensors are all stored in transparent cylinders that make up the main body of the robot. Holding this is a frame, which also houses any other necessary attachments, such as the rope guides, braking system, safety line harness, tube retainers, buoyancy attachments, and adjustable weights.

There are six main subsystems on the profiler: the physical frame, the weight and battery tubes, the computer and sensor tubes, the buoyancy system, the thrusters and rope guide, and the braking system. Each subsystem went through multiple iterations. The decision-making for each of these iterations will be discussed here.

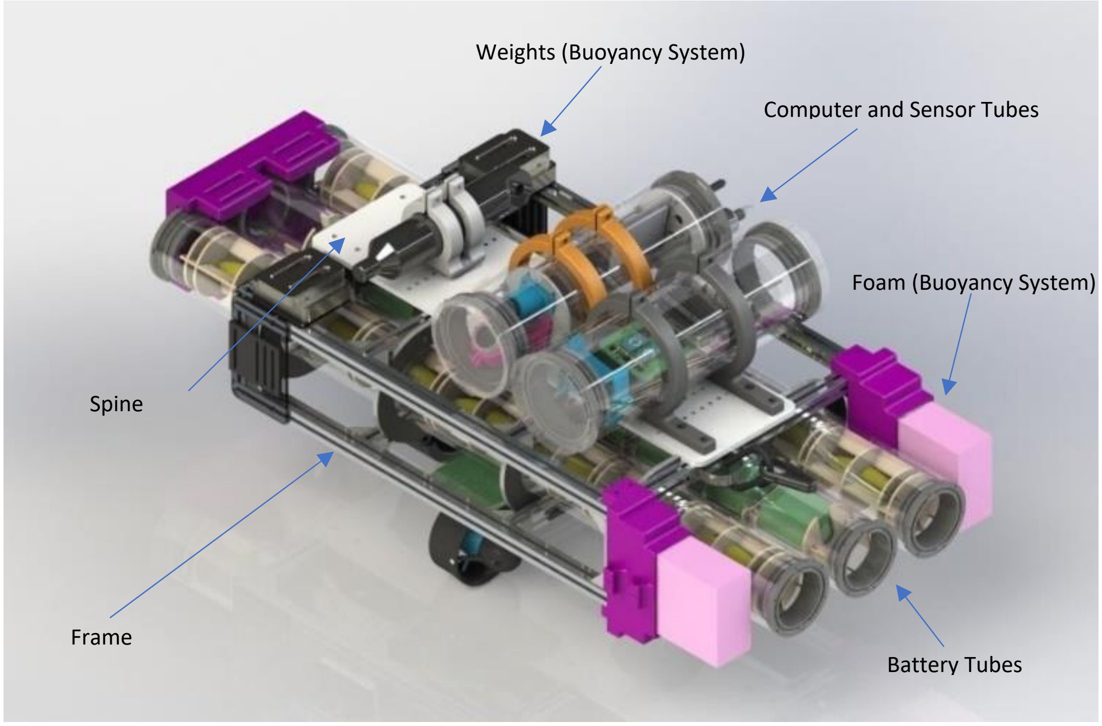

Figure 1: Final Render of profiler

The Frame

In actual open environments, the profiler will be dealing with currents, biofouling, sea creatures, and rugged conditions. For this reason, it must be robust.

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The initial active prototype was fragile and difficult to carry. Its frame was constructed of plastics, angle brackets made of sheet metal, and 3D printed handles. Yokes constructed from King StarBoard (a material commonly used in sailing contexts) functioned as both the cradle for the weight and battery tubes and as the support for the spines which held the thrusters, rope guides, and computer tubes. The handles were prone to breaking, and the frame itself was not secure. It was decided that a frame would be constructed from aluminum to increase the structural integrity of the profiler. Initially, a rectangular frame of 1-inch 80/20 aluminum stock was designed. Due to unnecessary weight, and the need for a positively buoyant overall robot, this was switched out for 2-centimeter stock. The sheet metal aluminum brackets were removed and replaced with horizontal bars that made up part of the frame. The starboard yokes and acrylic spine were bolted directly to this frame, resulting in a significantly more structurally sound setup.

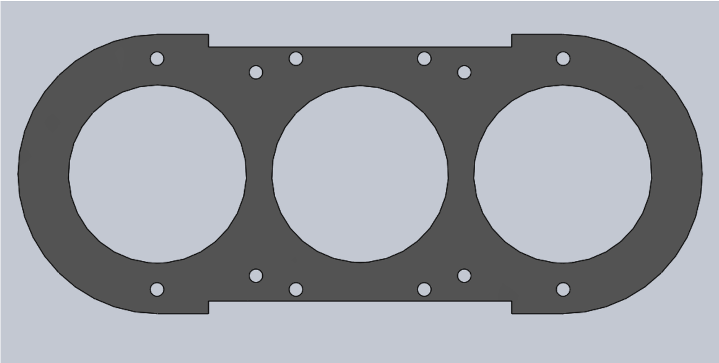

Figure 2: A yoke, four of which in series held the battery tubes and acted as the initial frame for the robot. The three larger holes acted as cradles for the battery tubes, while the smaller bolt holes allowed attachment of the spine via angle brackets.

Additionally, this frame functioned as a practical way to handle the profiler. The profiler weighs roughly 40 kilograms, and due to its shape often requires two people to be moved. The 3D printed handles were not strong enough to hold the robot and cracked frequently. The new aluminum frame makes it easy to grip onto and lift the profiler.

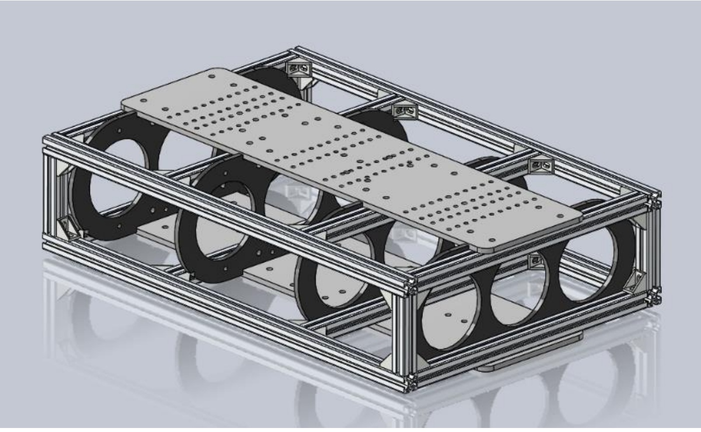

Figure 3: The new frame, constructed out of 2-centimeter aluminum 80/20 stock.

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Weight and Battery Tubes

The majority of the profiler's physical build is made up of the weight and battery tubes. Because profilers are sometimes deployed for weeks on end, they must have enough battery life to last for a significant amount of time. The profiler has three long tubes designed for housing the batteries to support this. As placeholders, two of them hold weights, due to the high cost of batteries. It was decided that for the current stage of research a full set of batteries was unnecessary.

There are three important components to take into consideration with the battery tubes. The contents of the tubes must be secure and unable to shift, so as to avoid the contents being damaged and the profiler's center of buoyancy being adjusted. They must be secured in such a way so that all of their weight is not resting on the deployed bottom end of the robot, or they will push the cap off and fall out. Lastly, they must all be wired together and run out from the housing tube through a single penetrator.

To secure the contents, a 3-dimensional rack constructed from 2-dimensional laser cut fiberboard is slid into the tubes, with batteries or weights slotted along its length. The perimeter of the rack sits flush with the inner diameter of the tube, and so it slides in smoothly and prevents the weights and batteries from shifting.

In initial stages of testing there was difficulty regarding keeping the racks in the tubes, as they tended to slide and push off the bottom end cap. To prevent the entire weight of the battery and weight racks from resting on the deployed lower end cap of the tube, threaded rods have since been run through the length of the battery rack and threaded into standoffs attached to the deployed top end cap of the tube. This setup puts retaining force on the top end cap, while putting no weight on the bottom end cap.

To supplement this, an external end cap retainer is attached to the bottom end caps of the three tubes. Two 3D printed components sit flush to the end of the tubes. A strap runs through the other side of the parts and gets buckled onto the frame of the robot, allowing no way for the end caps to come loose.

Penetrator caps are situated on each end cap. These are slots through which wires or removable vent caps can be placed while maintaining the waterproof quality of the tube. Slots in the battery rack allow for a wire to pass through, so that all batteries can be connected in parallel to a single line which is then run in series through each of the battery tubes and on to the computer tubes.

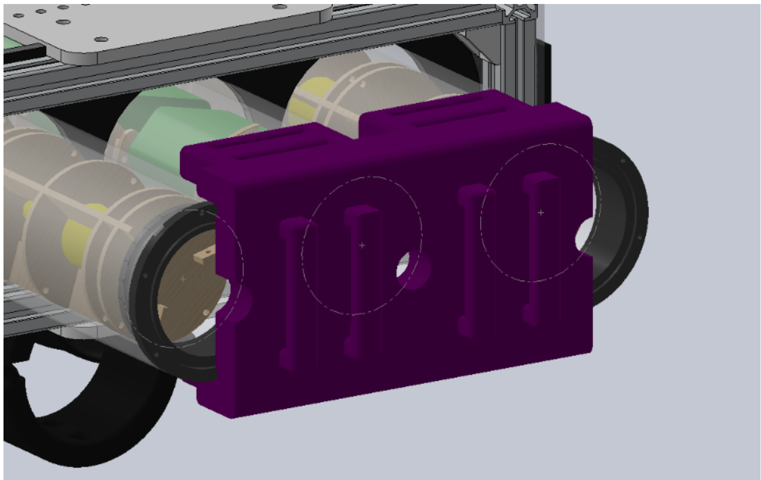

Figure 4: The external end cap retainers. They are strapped to the robot with a belt and can be easily removed and replaced.

Computer and Sensor Tubes

Two larger diameter tubes sit on the top spine of the robot and house the computer system that runs the profiler and all necessary sensors. They contain a Jetson, which is the microcomputer being used to run the system, a depth sensor, and a temperature sensor. Outside of the tubes is a dissolved oxygen sensor.

New sensors can easily be integrated into the system. One of the tubes is currently empty and is waiting to be filled with new sensors.

The Buoyancy System

As previously noted, the robot must be slightly positively buoyant. This will help ensure that the robot will return to the surface even if it loses power. However, in order for the profiler to be energy efficient, the profiler must not be overly buoyant, as this will fight the thrusters and necessitate a higher energy draw during dives.

Depending on the situation, the profiler may need to be more or less buoyant in order to be positively buoyant. For example, salt water and fresh water will have different effects on buoyancy, as buoyancy increases in salt water due to the water's increased density. Additionally, newly attached sensors could impact the specific gravity of the robot. This would result in need for adjustments.

As a solution, it was proposed to attach enough buoyancy to make the profiler very positively buoyant, and then have detachable weights that can be removed and reattached to adjust overall buoyancy. Dive weights were selected for their compact size and slotting that allows for easy attachment, while exceptionally low density closed-cell foam (that is not, however, rated for greater depths) was used to add buoyancy. 3D printed mounts are used to attach the foam to the robot. Long bolts, attached to a plate on the frame, act to hold the weights, which can be stacked atop each other. Nuts are hand-tightened for easy removal.

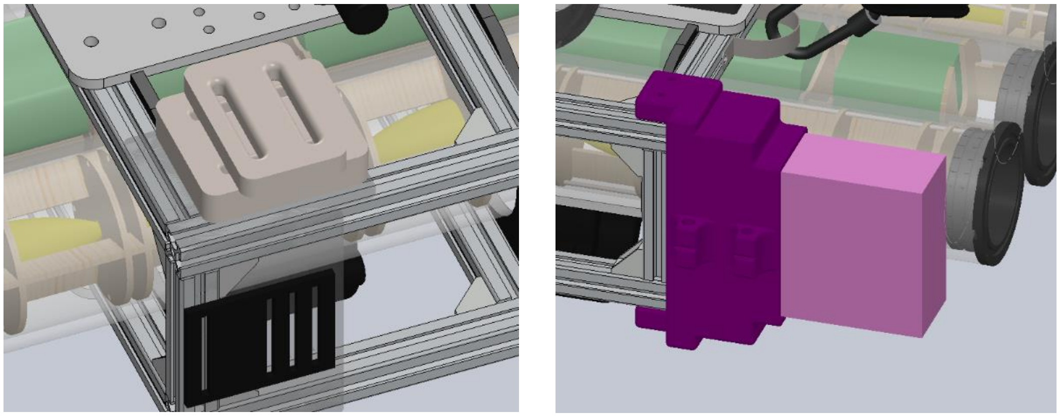

Figure 5: The buoyancy system. Left: Adjustable weights, consisting of one- and two-pound dive weights. Right: Buoyancy foam, mounted to the profiler with a 3D-printed mount.

As well as for adjusting overall buoyancy, it is also desirable to add ballast and adjust trim so that the profiler will maintain an upright position, as this is how it will be deployed. Unfortunately, the mistake was made to address both of these issues concurrently with overall buoyancy. Foam was attached to the deployed top end of the robot, to support holding it upright. This is acceptable, as the foam is not adjustable. However, the adjustable weights were then attached to an off-center position on the robot, so that they apply a torque around the center of buoyancy and adjust the trim of the robot. This results in the trim of the profiler being adjusted along with overall buoyancy as weights get added or removed. It is not possible to adjust one without adjusting the other.

Permanent weights should be mounted in the current position of the adjustable weights, the amount of buoyancy foam should be increased, and adjustable weights should be attached closer to the center of buoyancy on the robot.

Thrusters and Rope Guides

To move along a column of water, power and rope guides are needed. Two Blue Robotics thrusters mount to the lower spine of the profiler, and act as the source of locomotion. Between them, running in a line across the length of the spine, are two rope guides. The design used is simple; a cylindrical clip, which can be opened and closed for attachment to a rope.

The rope guides are 3D printed, and come in two parts, which are connected with hinges. Because of their make, they create a significant amount of friction with the rope if put at an angle. This requires that the trim of the profiler matches up with the guide rope, or that the design of the rope guides be modified.

The Braking System

Due to the need to have the robot return to the surface should it lose power, the braking system had to be designed in such a way that if power cut off it would disengage.

The brakes are meant to grip onto the guide rope that the profiler traverses, so that the robot can hover without need for powering the thrusters. This is to conserve energy, and so the brakes must also have low energy consumption. Several prototype ideas were proposed, including many which clamped onto the rope.

The design which moved into the prototype stage is a hydraulic-based brake. A water reservoir, attached to two pumps which can move water into and out of it, is attached to one of the rope guides. When it inflates with water, it pushes a bar with a textured surface across the rope guide, effectively closing it and causing the bar to grip onto the rope. Elastics hold the bar such that it naturally tends to be in an open state. A small leak in the reservoir requires that the water-in pump be engaged intermittently to keep the brake engaged. As a result, the brake will disengage gradually if power is lost.

Software

Code for the robot is currently basic. The profiler can dive, hover, collect data, and return to the surface. It can do this multiple times in series. The data can be graphed in real time on a connected computer. The hovering code is constructed such that at the desired depth, the thrusters will disengage. As the profiler begins to float back towards the surface, the thrusters will be engaged downward at low power. This is done in a loop.

Ideally, PID or other algorithms should be applied. Alternatively, the thrusters can be powered enough to counteract the positive buoyancy, and no further than that, resulting in near-perfect hovering. For the profiler, a thruster-powered design was chosen over a buoyancy engine, but it is worth noting that an additional buoyancy engine could be used specifically for braking. The problem with this idea, however, is that the buoyancy engine must automatically increase the buoyancy of the profiler if power is lost. That could be something to explore in future iterations.

To communicate with the profiler while it is submerged, a tether is used. For the scope of the project this was ideal, as other wireless solutions are much more costly.

It is desirable for the autonomy of the profiler to become more advanced. It should be able to dive to varied depths in response to feedback from sensor inputs other than depth. Eventually, a camera or other visual sensor should be connected, such that fish counts or other visually assessed data can be estimated.

Testing

Small-scale water tests were conducted intermittently with each new iteration of the robot, including buoyancy tests, thruster testing, trim testing, and rope guide testing.

Buoyancy and trim testing were often done concurrently and were carried out by placing the robot in the water and noting how much of the robot was submerged, as well as measuring the angle at which the robot sat. Weights and buoyancy were attached with zip-ties until desired trim and buoyancy were achieved, and positions of attachment were noted for permanent adjustments later.

Thruster testing was initially done horizontally, while the robot still lay flat as opposed to upright in the water. Lower speeds were found to be ineffective and were swapped out for higher power. After the trim had been adjusted such that the profiler stood vertically, the thrusters were tested for power for diving and surfacing.

To test the rope guides, a short woven rope was held manually by a person, and the robot was attached to it, then run for a short distance.

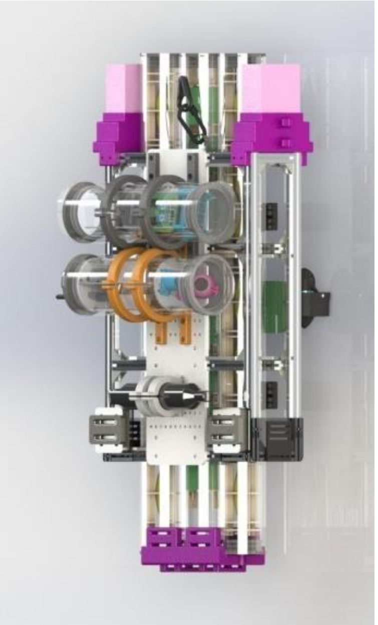

Figure 6: In final actual deployed position, the profiler sits upright. For initial tests, the profiler was mostly horizontal. The profiler is roughly 100cm long.

Results and Discussion

Final Testing

Final testing for the profiler was done at the MIT Sailing Pavilion along the Charles River.

The first test was done off of a dock. A boat was taken out about ten meters from the dock and dropped a tape measure with a weight attached to the end, so that water depth could be measured. It came out to be about four meters. The boat dropped an anchor, then returned to the dock and pulled the anchor rope taut, such that it rested at a 45-degree angle. The end of the rope was tied onto the dock.

The profiler was lifted, attached to the rope, and carefully placed in the water in its correct orientation. The correct depth was inputted into the code, and the thrusters were run.

The thrusters churned up water, but the profiler did not move. After several tests, it was concluded that the friction created by the profiler sitting vertically along a slanted rope was preventing the robot from diving.

The anchor was pulled up, moved directly below the end of the dock, and the rope was once again pulled taut. Depth was measured to be three meters and was inputted into the code, and the thrusters were run. The profiler dove successfully, stopping at the specified depth and returning to the surface. Once this was done several times, hovering code was implemented.

Hovering attempts were successful but choppy. The profiler moved up and down in jerky motions, which is less than ideal for nonintrusive maneuvers. However, general motion was consistent and smooth, as shown in Figure 2, which plots depth over time over three successively run dive tests.

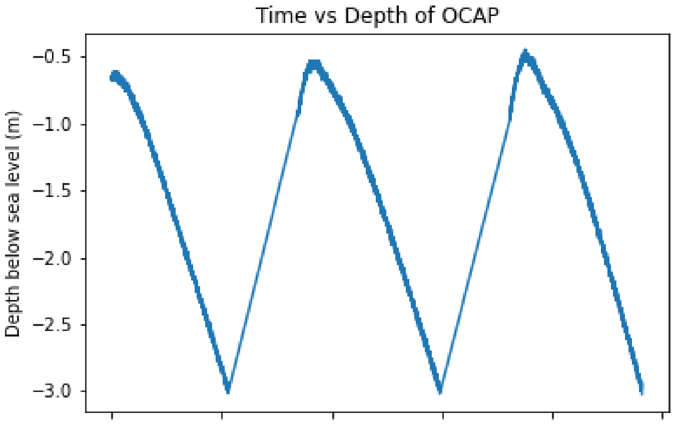

Figure 2 Depth vs. time over three successive dive tests

Following these tests, a boat was taken out to deeper water. Depth was measured intermittently until an ideal spot of nine meters was found. An anchor was dropped for stabilizing the boat, then a second anchor was dropped to act as the guide rope for the profiler.

Testing was successful. The robot was capable of diving to a specified depth, returning with either power or buoyant force, and diving again. Hovering code was modified to be smoother and was implemented successfully, such that the previous jerky back-and-forth motion was minimized.

Several practices were found to be useful for easy deployment of the bot. Having a boat that is low enough for a person to reach into the water, but stable enough such that it will not tip or sway, is ideal. It is helpful to have three people handling the robot. One or two people lift the robot from its cradle, while the remaining people secure the guide rope to the rope guides. The robot is placed back in its cradle, then moved closer to edge of the boat, where two people carefully lift and place the robot in the water while a third person holds the safety line and tether clear. A person holds the top of the mooring line taut. The programmer runs the tests. To lift the robot from the water, two people must lift it vertically until most of the robot is clear of the side of the boat, then the robot is turned such that it is flat and is placed onto the cradle.

The original expectation was that the robot would be deployed along existing mooring lines attached to buoys, but for the experiments a rope was held manually. It is uncertain as to how easily the profiler could be attached to a mooring line which is underwater.

Conclusion

The profiler in its current state is able to be deployed, dive, collect data, and return to the surface without problem. Testing showed that the current prototype is satisfactory for its scope. A single battery was used for the entire day of testing, implying that the hypothetical planned total of batteries will be more than enough for extended battery life.

Hovering code, as well as sensor-dependent code, could be further developed in the future. Learning to deploy the profiler at an angle could be useful in the future. The buoyancy foam broke off during handling at one stage. While it was easily replaced, it should eventually be switched out with a better system, such that it is not so fragile. Additionally, it must be replaced with something rated for greater depths. Better systems for retaining waterproofness of the tubes should be created, as the current system may not stand rugged conditions.

In its current state, the profiler does not have all relevant sensors installed. These should be added to the sensor tubes.

Acknowledgements

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References

Martinez-Porchas, Marcel, and Luis R. Martinez-Cordova. “World Aquaculture: Environmental Impacts and Troubleshooting Alternatives.” *The Scientific World Journal*, Hindawi, 29 Apr. 2012, https://www.hindawi.com/journals/tswj/2012/389623/.