Underwater ROV and Applicable Systems

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Research conducted by Chase Bonfiglio, Mathematics and Science Academy, Ocean Lakes High School. This engineering design project was done for a senior research project in the Math and Science Academy in addition to a practicum project for the Advanced Technology Center in junior year.

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Executive Summary

This project is based on research done in the Engineering Practicum at the Advanced Technology Center. A large amount of research and a loose design for a tethered underwater ROV was developed. This project entails the finalization and construction of the tethered underwater ROV. Furthermore, it serves primarily to equip the ROV with the necessary systems and software to be utilized in real-world research settings. By designing and implementing a water sampling mechanism, a conductivity, temperature, and depth sensor package, a photogrammetry system, and programming a dashboard and telemetry system, the ROV would be adequately suited for a proper research mission analyzing local marine environments and making decisions related to the growth and farming of oysters.

Statement of the Problem

With the current oyster population, it would require over a year for the entire bay to be filtered. Oysters filter food through their gills and can remove sediments and other contaminants that pollute the bay. They also consume algae and help to reduce nutrients like nitrogen and phosphorus which set the stage for several environmental issues[1]. The idea of using underwater ROVs to map the oyster population in order to more efficiently plant and harvest oysters has the potential for wide-reaching consequences. Such a device would have a large impact not only on the local oyster population and ecosystems but if successful, could have wide-ranging impacts including improving global climate health and the aquaculture industry.

Currently, a number of organizations are working to restore the total oyster population back to its peak, but unlike agriculture, aquaculture is rooted in outdated methods of farming with little modern technology in use. With an affordable underwater ROV, oyster farms or restoration sites using bottom culture would be able to scale their operations much more efficiently. With several sensors, ROVs could be used to collect a wide range of data to help farms make better decisions regarding their planting and harvesting. Using imaging sensors, data could be gathered to find hard surfaces where oysters could thrive without being buried in sediment. Imaging could also be used to evaluate the health and maturity of oysters. This data could help farmers create optimal dredging paths to harvest larger amounts of mature oysters without disturbing younger oysters. Additionally, sensors could gather data to find areas with optimal salinity and water depth.

Oyster restoration has the potential to drastically grow aquaculture in the economies surrounding the Chesapeake Bay. With continued investment in the restoration and maintenance of the oyster population, a wide range of jobs have been created. For example, in a single oyster reef restoration project in the Northern Gulf of Mexico, nearly 90 jobs were created[2]. Additionally, an increase in the oyster population would allow for a higher capacity of several popular aquaculture species in an industry already worth more than $30 million[3].

Design Objectives and Limiting Factors

There are five main portions of this project. The first includes finalizing the design of the ROV and its construction based on the prior years' work. This early work will serve as the foundation for the rest of the project.

The second is the design and development of a water sampling mechanism. The ROV design is based on an Arduino located on the ROV and as such, the water sampling mechanism must interface and be controlled by this central Arduino. Once collected, the sample must remain locked in a container for the remainder of the ROV's journey. One of the biggest difficulties with this ROV, which can be seen throughout the project, is the need for adequate waterproofing. Both the container holding the sample and whatever necessary electronics are required to trigger the sampling mechanism need to be waterproof; the container to prevent contamination of the sample and the electronics to keep them from shorting.

The third element of this project is the conductivity, temperature, and pressure sensor package. By gathering this information, oyster farmers may determine optimal locations to grow or harvest oysters. These sensors will be placed in a compartment that differs from the main electrical compartment as a failsafe measure. With the addition of more sensors and the need for them all to interact with the water outside the ROV, the risk of leakage is greatly increased. This compartment will once again require adequate waterproofing measures and demand wiring from this electrical sensor package back to the main electrical compartment with the main Arduino controller.

The fourth element of this project is the photogrammetry system. This consists of a GoPro mounted to the front of the ROV set to take images at a preset interval. Then, after a run, the images will be collected and fed through photogrammetry software in order to create a 3D image of the surrounding terrain. This portion of the project remains the most dubious as it largely hinges on the fact that the local marine environments are clear enough to get quality images to be fed into the software. Environments with high levels of turbidity would render this system effectively useless.

The fifth and final element of the project is designing a dashboard that can be connected to the Arduino to stream the information collected by the sensors in real time. This allows for better navigation and real-time analysis of the environment surrounding the ROV, by hooking up a laptop to the Arduino and importing the data collected from the COM ports into a Python program. NumPy and SciPi Python libraries can be used to create graphical visualizations of the data. Finally, a graphical user interface can be programmed with Tkinter and the graphs can be presented on a dashboard allowing for easy manipulation and exportation of the data collected.

Technical Approach

In order to complete the objectives as described above, a systematic approach was utilized to comb through any necessary considerations and develop the ROV and additional systems. This ensures that the project stays on track to fulfill the needs of oyster farmers and researchers alike.

Identifying User Needs

The primary users of this ROV are oyster farmers and researchers analyzing marine environments. After thorough research, key requirements include an affordable, portable design that has basic sensor capabilities such as a CTD sensor package while also including systems to image the ROV surroundings and take water samples. Additionally, scalability is extremely important for a research setting to allow the ROV to adapt to more specific needs within a particular experiment or investigation.

Target Specifications

The ROV must meet several criteria in order to be deemed complete and effective.

Waterproofing: The first specification is that the ROV must be waterproofed completely. This includes the electrical components such as the Arduino microcontroller and sensors and the locations where they interface with tether outside the ROV. Additionally, the water sampling container must be waterproof to prevent contamination of the sample and needs to be controlled remotely via the Arduino-based telemetry system.

Data Collection: The second criterion is the sensors and telemetry system must be accurate and provide real-time, reliable data without interference. Specifically, the pressure sensor must be tested for accuracy to ensure that the calculated depth of the ROV is precise.

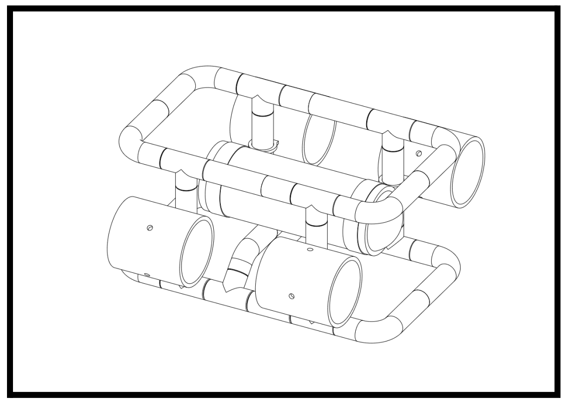
Data Visualization: Finally, the data must be presented in an intuitive manner that allows the user to analyze environments in real-time and export the data.

Generating and Producing Design Concepts

The Frame

In most home-built underwater ROVs, PVC piping is used as a cheap method of creating a frame and structure for mounting motors while allowing for space to hold wires and onboard electronics. In builds from both "Home Built ROVs" and "Bit Driven Circuits", a simple frame is constructed using PVC ranging from 1/2 in - 1 ½ in diameter with Tee and Elbow connectors[4][5]. The PVC is then often filled with expanding foam to prevent any water from leaking in to affect buoyancy. Furthermore, to adjust the buoyancy of the vehicle, an adjustable compartment must be located somewhere to store ballasts. This may come in the form of open-ended skids underneath the ROV or simple boxes in each corner of the ROV to store washers or some other dense material. For this project, a port was added to the frame to allow it to flood to achieve a neutral buoyancy.

To store the electronics, a larger PVC tube, usually around 4in, is used in conjunction with a clear plastic dome in order to house a camera with a useful field of view. This project continues with that standard utilizing a 4-inch PVC pipe, two end caps, and a removable rubber coupling. This allows for the internal electronics to be accessible after their initial assembly. On one of the endcaps, there is a hole large enough for a 2.5-inch acrylic dome to sit on while leaving a ledge for the dome to sit on. On the other end cap, four ½ inch PVC pieces were added around four holes to allow for the wires to penetrate the electronics compartment from the tether.



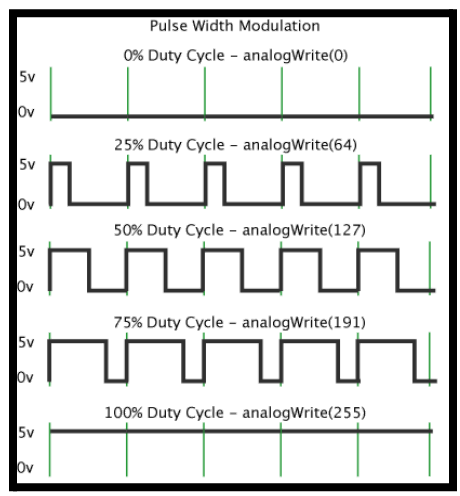
Lastly, as inspired by “A German Engineer” the YouTube Channel, the excess 4-inch PVC was utilized to create motor guards[6]. This allowed the motors to be mounted and removed easily and prevented debris from getting tangled in them.

Microcontroller

In order to collect data from sensors and communicate in real-time to the controller on the surface, a microcontroller was deemed necessary. A microcontroller is an integrated circuit possessing random access memory, processing cores, and input and output pins to integrate peripherals; essentially it's a mini-computer. Arduinos are a special type of microcontroller that contains an ATmega328P microprocessor and a number of pins for other electronics to connect to it. There is an Arduino integrated development environment (IDE) that allows for programs and code to be developed and uploaded to the boards[7].

Everything regarding the designs of the boards to the IDE is open source and over the course of nearly two decades, users have developed thousands of libraries to make programming and integrating complex electronics into Arduino projects much easier. Examples of these electronic components include sensors such as water pressure sensors, cameras with video feeds, and thermometers all of which need to be able to be implemented in this ROV. In order to communicate with these sensors, they need to be wired to pins of the Arduino of which there are two main types: Analog and Digital. Analog pins read a specific voltage from the device in order to communicate. While this allows for a large range of data to be sent, this is done at a relatively slow rate. Digital pins only have two states. They either return HIGH or LOW depending on if the voltage received is higher or lower than a threshold value and provide an extremely fast way to send and receive data[8].

In order to communicate more than two values, pulse width modulation is used. This mimics the analog range of communicated values at a much faster speed. Using a set frequency, a cycle consisting of a HIGH and LOW period is sent. By reading the percentage of the cycle that is HIGH, the Arduino can read a number between 0 and 255. This protocol can be used not only in receiving data but also when sending data. With motor drivers, an Arduino can be programmed to vary the voltage and adjust the speed at which the motors spin[9].



Telemetry Protocol

The underwater ROV design being used is tethered meaning that, from the control station where directions are sent and information received to the ROV, there is a long set of cables covered in a protective mesh. This design choice was made because many forms of wireless communication including radio waves function poorly through water and work much better through mediums such as air or walls. Sending data over long cables comes with its own set of challenges. Due to the longer length of the cables, the signals are subjected to voltage drop. This occurs as the wires inherently have a small amount of resistance. Over short distances, this doesn't factor into the signals. However, with such small voltages being used for the signals (0-5V) in the Arduino pins, over a long period of cabling, this voltage drop can significantly impact the signal. Additionally, even small electromagnetic waves can impact the voltage in the wire distorting the signal and resulting in faulty transmission. In order to combat these interfering signals, several electrical communication protocols have been developed. The main focus for this project is RS485.

With its ability to be used over long distances and resist electrical noise, it is the perfect candidate for this project. RS485 uses a twisted wire consisting of an A and a B wire. Instead of reading the voltage of a single wire like UART, RS485 reads the difference between the two wires. When the signal is altered with electrical noise, the differential voltage remains the same as the A and B voltages are altered equally. However, on the Arduino, serial communication is done over the Universal Asynchronous Receiver-Transmitter protocol. In order to use RS485 with an Arduino, a separate module was required to send and receive the differential voltages. Below is a diagram displaying the RS485 differential voltage signal[10].

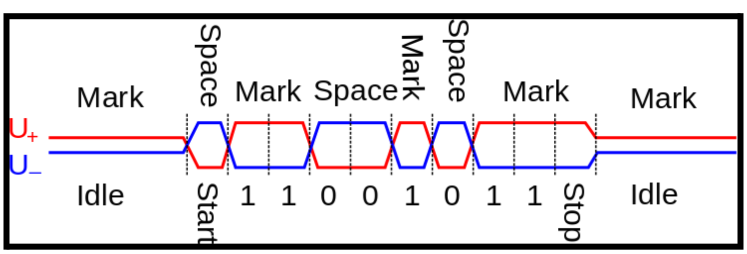


Image displaying example voltage from Wikipedia[11]

Photogrammetry

Photogrammetry is a method of creating 3D models of an object or environment by using large amounts of pictures. These pictures need to overlap and a program is used to identify these overlapping sections from different angles. Within the overlapping photos, either manually or automatically, the software identifies “light ray intersections” or the same point in space represented in two or more different photos. Based on several of these points, the software can use complex mathematics to triangulate its position and angle in relation to the points. Once this is determined for hundreds if not thousands of photos, the software can then compute geometry such as lines and planes which represent the object or environment. Some examples of these programs are Agisoft Meteashape, 3DF Zephyr, and Visual SFM[12,13].

For this project, the use of photogrammetry was intended to aid in the oyster dredging process. One of the many ways oysters can be farmed is through dredging. This method involved dragging and fishing nets along the bottom of the ocean floor in order to catch oysters and other marine life. However, dredging can have major consequences as, with the imprecision involved, it is very common to afflict damage to the marine ecosystem[14]. Reefs and grass beds are often torn or broken in the process[15]. Although this method is not as common as it once was, it is still used by some oyster and aquaculture farmers with the correct permits. One way to reduce such damages is to map optimal paths along the seafloor which maximize aquaculture catches while minimizing damages to the environment. By creating three-dimensional models of the oyster growth in specific areas, especially those with low visibility from the surface, farmers can make more informed decisions when it comes to harvesting.

Additionally, in restoration projects, photogrammetry can be used to better map out the growth of oyster reefs and track a project's progression. By using 3D models of the reefs, more accurate counts of the oysters and more detailed visual inspections can be performed. An underwater ROV provides a noninvasive method of gathering important data for researchers. When compared to alternatives such as lidar and other technologies, photogrammetry is much more cost-effective simply requiring an underwater camera such as a GoPro to operate. This function also opens up the opportunity for machine learning algorithms to be integrated in order to count and inspect these reefs. This idea was inspired by work from Professor Yiannis Aloimonos is doing at University of Maryland. Utilizing a GoPro Hero 7 Black to gather video footage, a convolutional neural network could process that number of oysters across frames ensuring accurate counting[16].

For implementation into this project, by incorporating a GoPro Hero Silver onto the ROV, pictures would be taken at a preset time interval (ex: every 5 seconds). The controller would then be required to navigate around a feature in order to gather the images required to create a 3D model.

Sensor and Water Sampling Containers

Whilst there is an electronics compartment integrated into the design, the sensors, when interfaced with the water, provided the greatest opportunity for leakage. Both the temperature sensor and pressure sensor required additional ports to access the surrounding environment and, if damaged, could allow water to short any components around it. In order to prevent this possibility, these sensors sit in their own dedicated compartment. In a 4-inch long piece of 4-inch PVC, both sensors poke out an endcap.

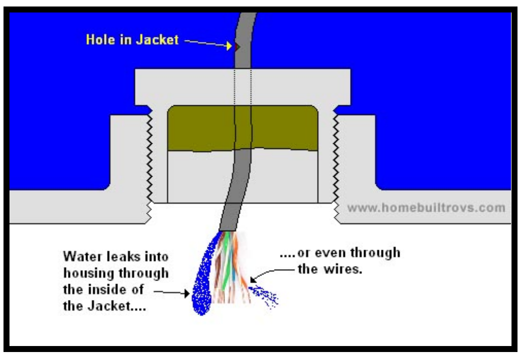
Currently, in order to acquire water samples at specified depths, most operations use a Nansen or the improved Niskin bottle. These devices function as bottles with two end caps and are lowered into the water opened. At a specified depth, a weight is released which inverts the bottle thus sealing it[17]. Usually, this device is accompanied by sensors that measure the temperature, pressure, and conductivity of the water. In larger-scale operations or when several samples are required, a rosette is used. This is a frame that holds multiple Niskin bottles and contained in it is the CTD sensor package. The primary reason for a design such as this is to be able to make it easily operable from the surface of the water[18].

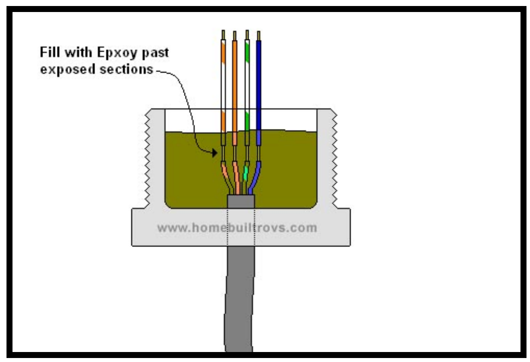
However, in this project, due to the smaller nature of both the device and the environments that it is designed for a Niskin-based device proved to be infeasible. On the budget allotted, constructing a mechanical device that interfaced with the Arduino and remained waterproof seemed unlikely. However, the ROV already included a device capable of pumping water into a dedicated hose. An additional bilge pump, the component used as the motors for the ROV, could be attached to a water sampling container to allow for water samples to be collected. A relay was necessary to ensure the functionality of the bilge pump. When testing the relay with an advertised voltage input range of 4.5-12 volts, it was discovered that the lower end of this range provided insufficient current to activate the relay instead of only triggering the indicator light. The Arduino Mega only outputs voltages up to 5 volts so a workaround was required. Utilizing a 2N2222 transistor in between the 12-volt battery and relay, the Arduino Mega could activate the relay with minimal current. In order to prevent water from flowing in and out of the container at undesirable times, a check valve is placed in the middle of the excess hosing.

When programming the controls for this mechanism, one of the empty buttons on the PlayStation controller was used for activation. The bilge pump used was rated to pump at 1100 gallons per hour. With a 4-inch PVC pipe and a length of 4 inches, the volume of the PVC was approximately .22 gallons. By powering the bilge pump for .72 seconds, the water container would be completely filled with water.

Waterproofing

The main method used to feed wires in and out of the PVC whilst preventing leakage was creating a well of epoxy for the wires to sit in. With an ½ inch PVC pipe and an ¼ inch length, a well could be created to hold the epoxy. However, if bundles of wires were fed through this well and the jacket of the bundle got cut somewhere along the tether, water would have the opportunity to leak in essentially through the wires themselves. In order to prevent leaking of any kind, insulation on the wires was removed when they went through the epoxy. Refer to the diagrams below courtesy of "Homebuilt ROVs" to see an example[4].





Results

Telemetry

The implementation of the RS485 telemetry modules proved to be very successful. The PlayStation controller, pressure sensor, and temperature sensor all functioned well up to a 9600 baud rate and allowed the Arduinos to communicate these values roughly 40 times each second.

Water Sampling Device

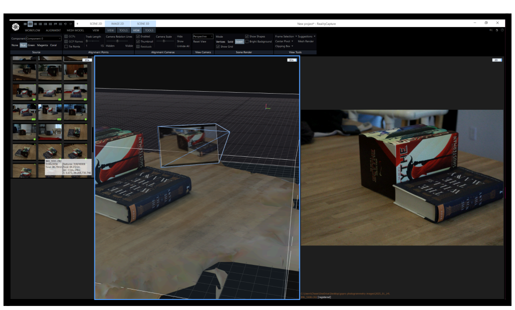
This mechanism proved to be effective but its applicability is yet to be determined. The container didn’t fill completely when tested as the end caps provided additional, unaccounted-for volume. However, the main concern when testing was that, as the bilge pump collected water, it was unintentionally filtering the sample. Further research and consultation with experts in environmental science are required to determine the value of these samples.

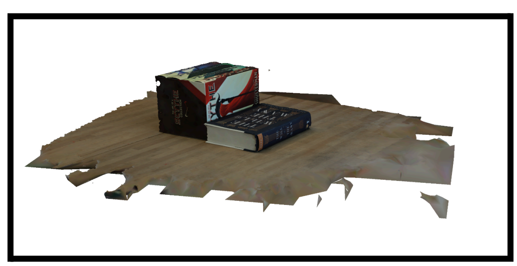
Sensors

Both the sensors proved to be functional and the container that housed them didn’t leak on the first operation underwater. Unfortunately, it seems that the pressure sensor isn’t calibrated correctly leading to incorrect depth readings. Additionally, temperature readings could be used to further hone in on the depth readings as the pressure should be slightly affected by the water temperature.

Photogrammetry

This part of the project was the biggest failure of the project. When initially testing the software (RealityCapture) with a DSLR camera, the 3D models turned out well with a lot of detail. The stack of books imaged was able to be captured in enough detail to read the text on the front and back of each book as can be seen below.



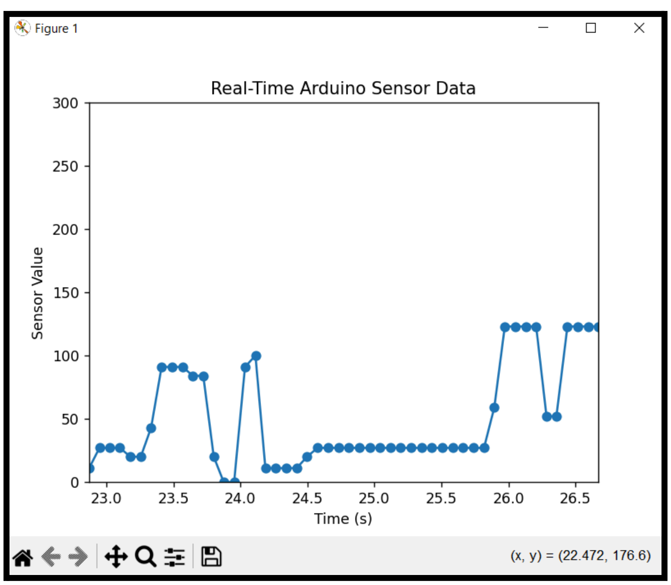


However, when attempting to get photos underwater with the GoPro, the images captured did not hold enough detail for the software to properly model the environment. Whilst the extremely wide angle of the GoPro certainly did not help, the main culprit of this issue likely lies in the turbidity of the water images. The large amount of debris in the Chesapeake Bay and its lack of clarity proved difficult to image and when close to features, the software lacked enough common reference points to create a 3D model.

This function may be useful in a different environment with lower turbidity such as freshwater locations but, in the Chesapeake Bay, this feature is rendered useless without advancements in the photogrammetry software or high-quality images.

Data Visualization

Utilizing the MatPlot Python library, creating real-time graphs based on the Arduino serial outputs was pretty straightforward. After configuring the COM ports (there were some security precautions preinstalled on the computer preventing Python from accessing certain ports), a simple program configuring the bounds of the graph and axis labels was all that was required. One of the resulting graphs can be seen below.



Budget

Electronics					
Part	Figure	Quantity	Description	PPU($)	Total Cost($)
Elegoo Mega Board (Same circuit as Arduino Mega)	1.1	1	Used for the onboard control and telemetry	20.99	20.99
Arduino Uno	1.2	1	Used for surface controls and interfaced with the PS controller	27.00	*0
Playstation 2 Controller	1.3	1	Used joysticks and buttons to control the ROV	9.99	*0
RS485 Modules	1.4	2	Used to encode and send commands and data via the tether while mitigating interference and data loss over a long-distance wire	4.00	8.00
Cat 6 Tether	1.5	1	Used to send telemetry data between the Arduinos and supply power to the motors	20.00	*0
Braided Wire Covering	1.6	1	Used to protect Cat 6 wiring underwater	8.99	*0

BTS7960 Motor Drivers	1.7	6	Used to vary the voltage to the motors allowing them to be controlled via pulse width modulation (PWM) and the direction of the propeller	6.00	36.00
GoPro Hero 7 Silver	1.8	1	Used to record footage of the ROV's expeditions	195.79	*0
Bilge Pump 500GPH	1.9	6	Used to mobilize the ROV	15.99	*0
Prototyping Boards	2.0		Used to solder all of the electronics together to create secure connections and avoid loose wires	9.99	9.99
Arduino Connecting Wires	2.1	~	Used to connect the motor drivers and Arduino to the prototyping boards	*0	*0
Copper Wire	2.2	~4ft	Used to connect the PS controller and electronic components on the prototyping board	9.99	*0
Power Supply	2.3	1	Used to power the ROV	39.99	*0
Total Cost: $74.98					

PVC and Additional Materials					
Part	Figure	Quantity	Description	PPU($)	Total Cost($)
4in Rubber PVC Cap	2.4	1	Used as a removable cap for the electronics compartment	9.81	9.831
4in x 1- ft PVC Sch40	2.5	1	Used as the electronics compartment and motor guards	34.58	34.58
1.5in x 10 ft PVC Sch40	2.6	1	Used to build frame	12.78	12.78
1.5in PVC Tee Sch40	2.7	12	Used to build frame	1.92	23.04
1.5in PVC Elbow Sch40	2.8	10	Used to build frame	.96	9.6
PVC Cement and Primer	2.9	1	Used to connect PVC together	8.88	8.88
Epoxy and Primer	3.0	1	Used to seal wiring hole		*0
Velcro Pack	3.1	1	Used to secure motor drivers to 3D printed shelving	4.00	*0
3in Plastic Dome	3.2	1	Holds Camera	8.00	8.00
Sch40 4in PVC Cap	3.3	1	Used to cover end	5.00	5.00
Total Cost: $111.71					

*Marked items were acquired from either previous personal projects or the Advanced Technology Center's existing resources

Professional Skills

Prior Qualifications

Prior to this project, research was conducted on the oyster population in the Chesapeake Bay and existing projects similar to this one. This is located in a literature review written in the Fall of 2024.

My engineering background includes a Certified SolidWorks Professional Certificate in Mechanical Design and three years of Engineering Technology at the Advanced Technology Center where I built projects in all of the different engineering disciplines.

Communications with Expert

For this project, two experts were consulted: Ken Garrison, an Engineering Technology II Teacher at the Advanced Technology Center, and Dianna McDowell, a Brock Environmental Science Center Teacher.

In order to gain insight into the desired functionality of the ROV from a researcher's perspective, Dianna McDowell shared her thoughts. These mainly consisted of basic sensor functions and water sampling capabilities with the possibility for future/existing devices to be mounted onto the ROV.

For the construction of the ROV, Ken Garrison was consulted. Advice on assembling the PVC frame and waterproofing the device was utilized.

Conclusion

Overall, this project was extremely successful. The underwater ROV is now able to successfully gather pressure and temperature data, relay such information over a tether, and present it on a digital display for immediate analysis. The ROV is also able to collect water samples which allows for at least some further analysis even if some properties of the sample such as turbidity may be inaccurate. Compared to similar projects, it aligns with its results providing a low-cost device to investigate marine environments. It does however include designs that provide purpose to this class of devices (budget DIY ROV projects) implementing water sampling and sensor packages. Overall, this project adds to the existing body of knowledge supporting the utility of smaller-scale budget ROVs for research and potentially oyster farming.

Personal Reflection

As I continue to work on this project, there are a couple of main areas I plan on addressing. The first of which is the optimization of the current design. The pressure sensor requires further calibration in order to more accurately calculate the depth of the ROV. The soldering and PVC construction in some locations is subpar and, in order to ensure a longer life span of the ROV, will likely require replacement utilizing the skills I've honed over the course of this project. Finally, revisions to the water sampling mechanisms may be necessary depending on the consultation of researchers and determining how the bilge pump may alter the water samples. The second area that can be improved on in this project is the sensor package. An increased budget or some creative designs, including more sensors would enhance the level of detail the ROV could collect about its surroundings. Lastly, I plan on attempting to incorporate machine learning into the ROV to remedy the issues regarding photogrammetry. With proper programming, the ROV may be able to learn how to navigate around a feature and optimize its collection of imagery to better suit the needs of existing photogrammetry software.

Throughout the course of this project, I've improved my computer-aided design, circuit design, electrical engineering knowledge, soldering skills, and understanding of environmental science. The plethora of problems in both the construction of this project and the programming furthered my perseverance and problem-solving for future projects. I've learned to plan for these setbacks and adapt accordingly. Additionally, I've come to understand how to undertake larger research projects and how to apply all of the knowledge and skills from the past twelve years of education to better the world around me. This project has been an invaluable experience and I expect it to pay dividends in the rest of my engineering career.

Works Cited

1. Modeling approach to predicting nitrogen removal by the Eastern Oyster Aquaculture Industry. NCCOS - National Centers for Coastal Ocean Science. 2025 Jan 9 [accessed 2025 Jan 30]. https://coastalscience.noaa.gov/project/predicting-nitrogen-removal-by-the-eastern-oyster-aquaculture-industry/

2. Economic benefits and impacts from two oyster reef ... [accessed 2025 Jan 31]. http://www.oyster-restoration.org/wp-content/uploads/2013/02/oyster-restoration-study-kroeger.pdf

3. Modeling approach to predicting nitrogen removal by the Eastern Oyster Aquaculture Industry. NCCOS - National Centers for Coastal Ocean Science. 2025 Jan 9 [accessed 2025 Jan 30]. https://coastalscience.noaa.gov/project/predicting-nitrogen-removal-by-the-eastern-oyster-aquaculture-industry/

4. Thone S. Homebuilt Rovs. [accessed 2025 Jan 30]. https://www.homebuiltrovs.com/

5. ROV frame construction. ROV Frame Construction using PVC pipe. [accessed 2025 Jan 30]. https://bitdrivencircuits.com/ROV/frameConstruction.html

6. YouTube. [accessed 2025 Jan 30]. https://www.youtube.com/watch?v=xKTcwbR1T9U&list=PLmSYQkT021zq8v4iVoVfW8mPkheygxaAa

7. Team TA. What is Arduino? Arduino. [accessed 2025 Jan 30]. https://www.arduino.cc/en/Guide/Introduction

8. Docs.arduino.cc. [accessed 2025 Jan 30]. https://docs.arduino.cc/learn/microcontrollers/digital-pins/

9. Pulse width modulation. Pulse Width Modulation - SparkFun Learn. [accessed 2025 Jan 30]. https://learn.sparkfun.com/tutorials/pulse-width-modulation/all

10. Docs.arduino.cc. [accessed 2025 Jan 30]. https://docs.arduino.cc/libraries/arduinors485/

11. RS-485. Wikipedia. 2024 Nov 6 [accessed 2025 Jan 30]. https://en.wikipedia.org/wiki/RS-485

12. Agisoft metashape. Dive Addicts. 2023 Feb 1 [accessed 2025 Jan 30]. https://www.diveaddicts.com/product/agisoft-metashape/

13. Deckner A. Best photogrammetry software in 2024: The ultimate guide. Sculpteo. 2024 Aug 30 [accessed 2025 Jan 30]. https://www.sculpteo.com/en/3d-learning-hub/3d-printing-software/photogrammetry-software/

14. Dredging activities and the potential impacts of ... [accessed 2025 Jan 31]. https://www.westerndredging.org/phocadownload/ConferencePresentations/2010_SanJuanPR/Session2A-EnvironmentalAspectsOfDredging/1 - Wilber - Dredging

Activities and Potential Impacts of Sedimentation and Resuspension on Oyster Reefs.pdf

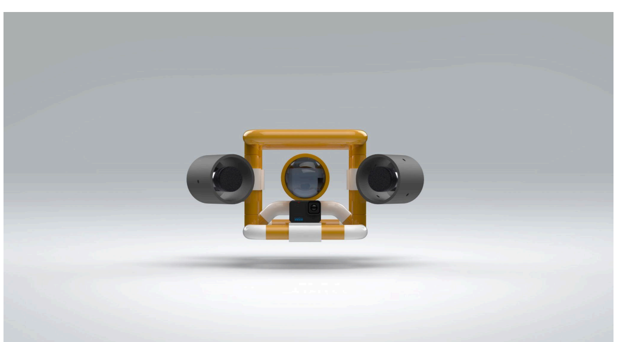
15. Survive CTB. Dredging up a debate. Chesapeake Bay Program. [accessed 2025 Jan 30]. https://www.chesapeakebay.net/news/blog/dredging-up-a-debate

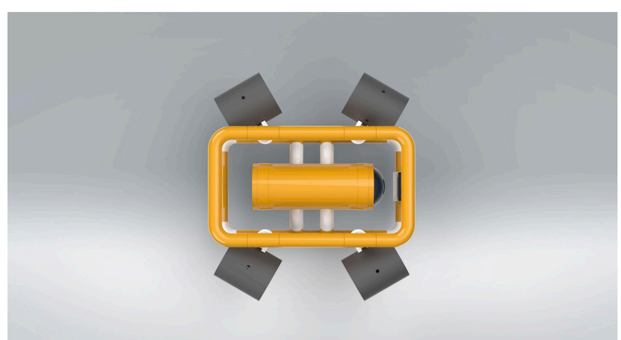
16. Using underwater robots to detect and count oysters. Using underwater robots to detect and count oysters | Institute for Systems Research. [accessed 2025 Jan 30]. https://isr.umd.edu/news/story/using-underwater-robots-to-detect-and-count-oysters

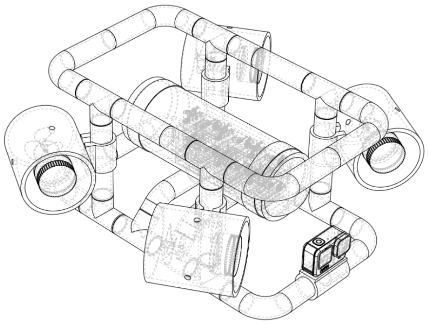
17. Aquatic. Find out more about the niskin bottle. Aquatic BioTechnology. 2018 Sep 11 [accessed 2025 Jan 30]. https://aquaticbiotechnology.com/en/noticias/find-out-more-about-the-niskin-bottle

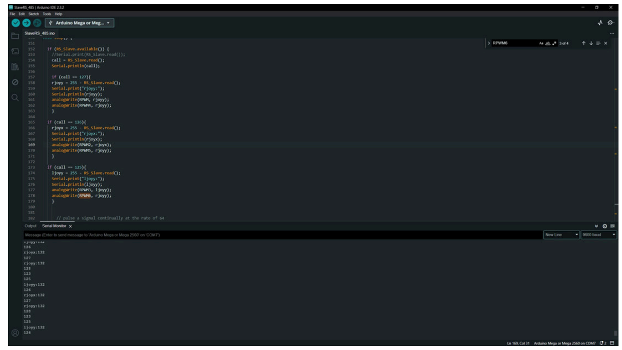
18. CTD Rosette • Mbari. MBARI. 2022 Nov 25 [accessed 2025 Jan 30]. https://www.mbari.org/technology/ctd-rosette/

Appendix

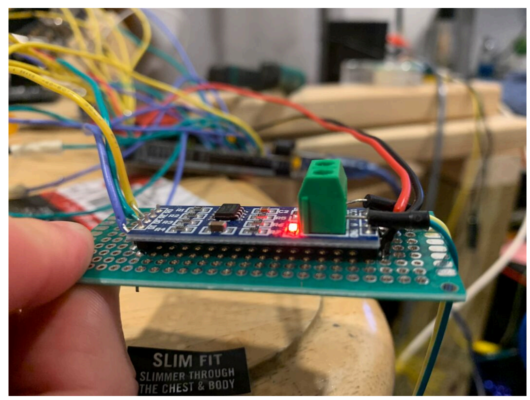









TFT color monitor
V1/V2
MENU


SLIM FIT
SLIMMER THROUGH
THE CHEST & BODY