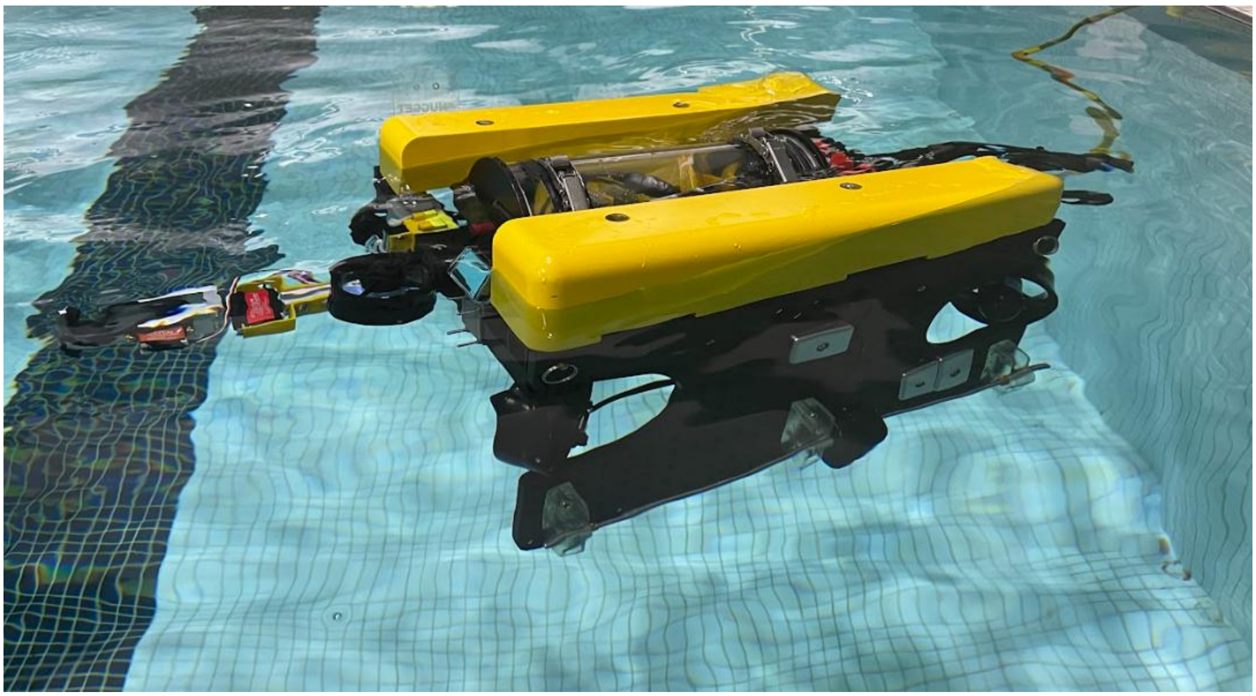
NUGGET Industries
WIT IEEE Underwater Robotics Team

WUROV [2022-2023]



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I. Introduction

A. Abstract

Wentworth Underwater Remotely Operated Vehicle (WUROV) is a multidisciplinary, collaborative company of passionate employees with the mission of contributing to underwater exploration. Expertise varies among employees, as the company is divided into three sub-teams (electrical, software, and mechanical) to suit the needs of the individual challenges and the overall system goals.

The company has spent the past 7 months successfully producing the third WUROV full-scale machine to date. WUROV is designed to complete challenges derived from real-world underwater ROV operations. These environments are historically problematic: human biology along with sheer size create limitations in efficiency and concerns for safety. WUROV eliminates these barriers.

WUROV has been proven capable of reducing plastic pollution in Mother Earth's water supply, repairing and restoring coral reef health destroyed by human-impacted climate change, and maintaining healthy waterways in the Delaware river and bay. The final product is a sleek machine: a result of effective planning and organization, extensive research and development, iterative design, manufacturing, wiring, programming, and testing. This technical documentation outlines the development process that resulted in WUROV being a top contender ROV to meet the Request for Proposal (RFP) put forth by the customer.

II. Design

A. Design Evolution

The proposed system utilizes the NUGV ROV chassis, shown in Figure 1, which was designed and assembled by previous members of Wentworth's IEEE chapter. The vehicle is 20in by 16.5in by 14.5in.

B. Mechanical Design

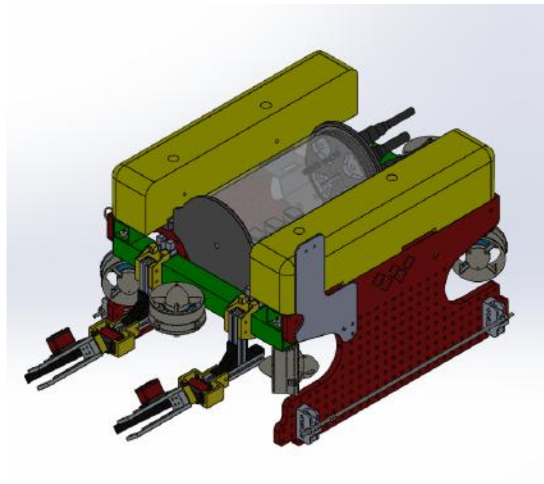


Figure 1: WUROV 3D Model

1. Frame

The frame of our ROV passed down from previous team members is made of 6061 Aluminum rectangular tubes. Four of these tubes are fastened together in a rectangular shape, one pair layed on top of the other and fastened with screws. This frame supports all parts of the ROV including, electronic housing, thrusters, a camera, a light, and two robotic grippers. The housing is held in place by a cradle secured across the frame and all other components are either fastened into the aluminum frame or around it. On opposite sides of the frame are the side walls/upright support for the ROV. The side walls are made of Marine-Grade HDPE plastic with a grid of holes for adding components.

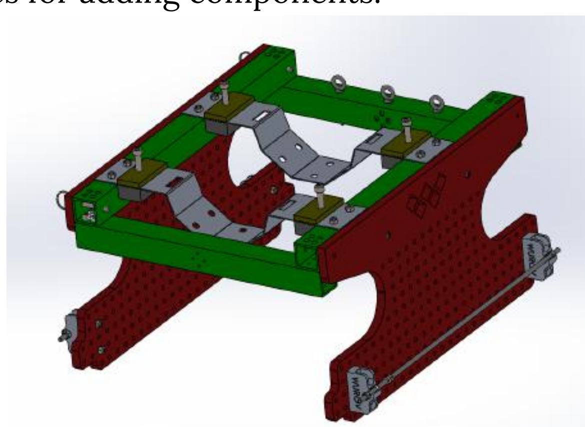


Figure 2: WUROV Frame

2. Electronics Housing

We use a blue robotics watertight enclosure for housing our electronics. This enclosure includes the tube and the flange. Our tube is made of cast acrylic and an aluminum end cap. Molded to the end cap is our pressure release valve which creates a vacuum within the enclosure. On the opposite side is the flange cap which keeps a watertight seal on the enclosure as a result of the o-rings surrounding the inner edge. Our electronics are attached to the inside of the flange cap via two metal rods and the ports for the tether emerge on the outside of the flange cap. These ports are surrounded by o-rings to reinsure a watertight seal and certain wires are epoxied into the flange cap.

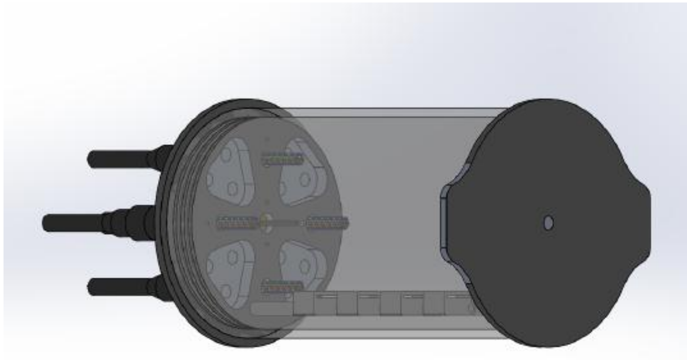


Figure 3: WUROV Electronics Housing

3. Buoyancy

The buoyancy for our ROV is controlled by adding or subtracting weight from the ROV. Using the holes in the side wall, a rack for lead weights has been attached and several aluminum plates have been fastened. To lower the overall density of the ROV Blue Robotics Subsea Buoyancy Foam was bolted on top of the frame. This poses the challenge of readjusting the weights on the ROV when going on missions in different pools at different locations.

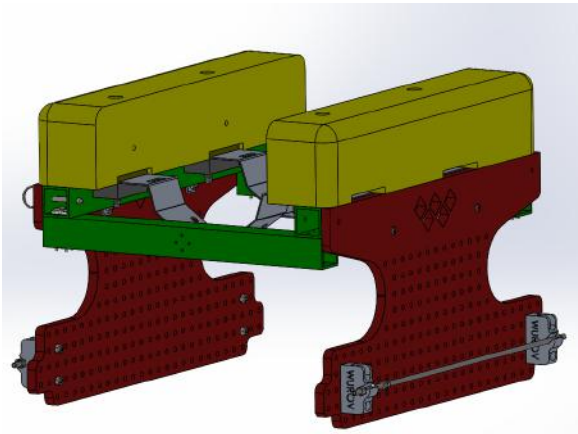


Figure 4: WUROV Buoyancy Devices

4. Thrusters

For maneuvering the ROV we currently use 6 T100 Blue Robotics thrusters which allow the ROV to move forward, backward, side-to-side, up, and down. All 6 thrusters are controlled by a flight stick at the control station.

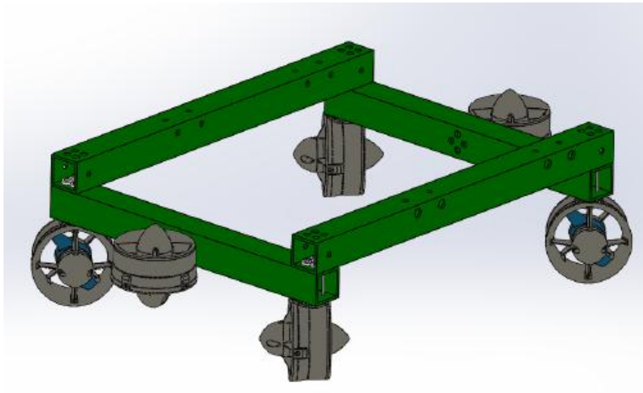


Figure 5: WUROV Thruster Configuration

C. Electrical Systems

1. Modular Backplane

a. Overview

The backplane of the ROV is a long PCB with the female ports of backplane connectors soldered to it. One of these backplane connectors will contain three ground rails, three 12V rails, 12 PWM signal pins, two I2C pins (SCA, SDL), five 5V power pins, and 5 GPIO pins. Each board carries one of these connectors, providing a stable and secure connection to the backplane, while also allowing it to receive power and data.

b. Power Distribution

Power is taken from the wall and converted to 48V at 20A via a ground station power supply. Proper safety measures such as fusing connectors, and placing a fan on the ground station are implemented. This power is then transmitted via tether to the ROV. Using BlueRobotics waterproof sealing connectors, we are able to deliver the power on board in our waterproof electronics environment. This power goes into two plug in 12 V power conversion modules that convert the input 48V to 12V, supplying sufficient power to the 12V rail on the backplane. The 5V converters receive power from the 12V converters as well. The 5V converters then supply the power rail on the backplane with power. The

ROV has an isolated ground from the power supply, as the ground pin of the waterproof connector is not populated at the control station. The isolation of the ROV ground protects the signals and feedback from enhanced noise when traveling up the tether via the ethernet connected to the pi, and will prevent common-mode voltages that will hinder the functionality of some of our components.

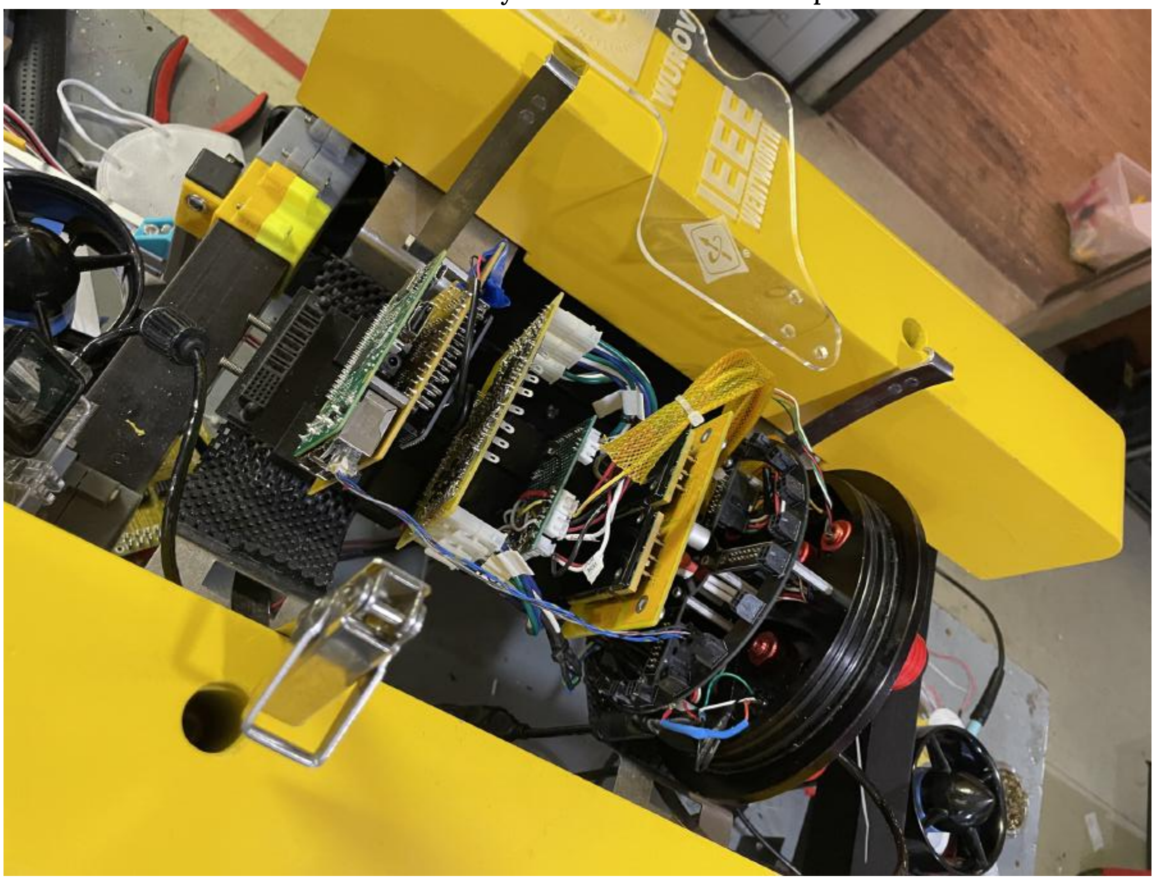


Figure 6: Power distribution board (First PCB on the right)

c. ESC Control

In order to effectively deliver power and PWM signal to the thruster motors that control the ROV on the X,Y, and Z, electronics speed controllers (ESC)'s were chosen. The ESC's used were basic ESC from blue robotics, handling anywhere from 7-26 V and up to 30 A. We used these ESC's at 12V, with a max current previously stated as 30A. The ESC has a PWM input that is tied to the PCA module on the sensor board, controlled by the Raspberry Pi. Because we have six directional thrusters, there are six ESC's on the board, each tied to its own PWM signal that is adjusted via input from the control station.

Figure 7: T100 Basic ESC by Blue Robotics

d. Sensor Board

The sensor board is a PCB that houses the Raspberry PI, PCA module, and is very interfaceable. The sensor board has slots for 5 analog video op amps if we decide to use an analogue camera, or even if we need to isolate an analog signal, the option is present. The Raspberry PI is a module that functions as the on board brain of the ROV, handling the input functions from the ground station, managing a digital camera signal, and communicating with the PCA via I2C (SCA SDL) on how to adjust the duty cycle output of the motor driving PWM signal. The PCA is a 16 channel 12 bit module by ADAFRUIT that will adjust the PWM duty cycle that is being input to the ESC's and encoders of the mechanical arm servo motors. This PWM duty cycle manipulation allows us to control our speed.

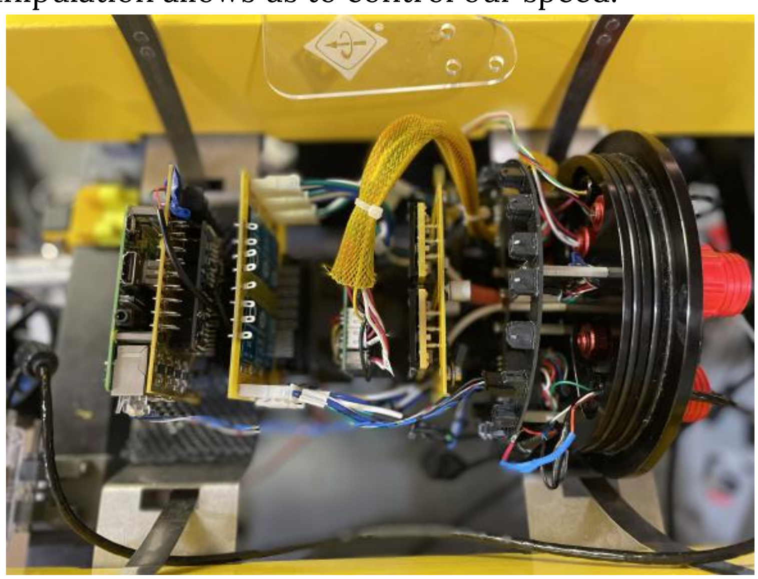


Figure 8: Sensor board (First on the left)

e. Subsystem Control

The subsystem control consists of a three stage communication between our surface control, Raspberry Pi, and PCA. First, the independent variable, the input is determined via a joystick controller stationed on our surface site. The data input of the joystick is communicated to the Pi via ROS**.** The Pi and PCA are streamlined on the same board mentioned previously, the sensor board. The Pi sends PCA signals which determine what PWMs need to be sent to our individual outputs. The potential maximum number of outputs we can control with the PCA is 16 but in our case we only need 14 separate PWMs. The method of communication we used to deliver signals between the pi and PCA is a program called I2C.

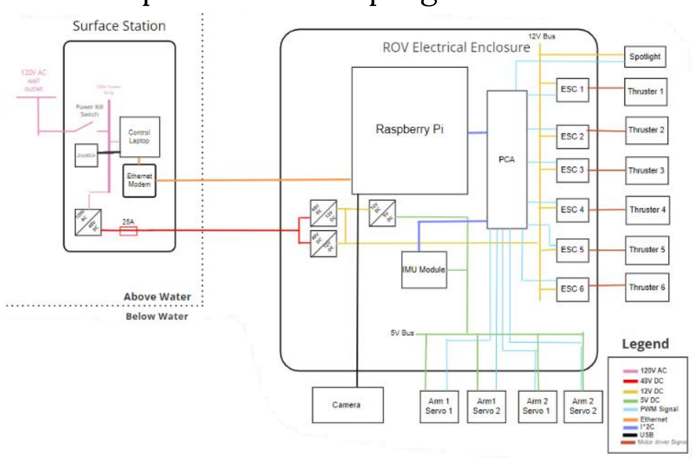


Figure 9: Surface control (Top left) and the Subsystem control (Right)

2. Tether

a. Surface Side

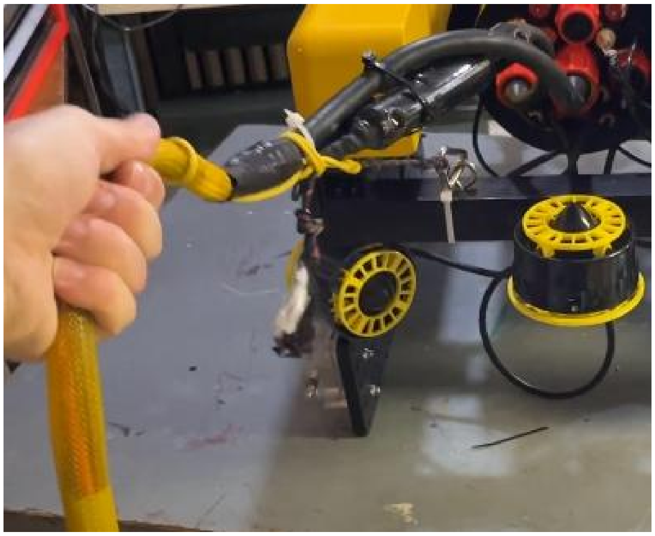
For the surface side of the tether, we chose to use a standard use extension cord that will receive 120V from a wall receptacle and feed that into the on surface power supply. The on surface power supply will step down the 120V to a 48V/20A feed into our laptop and control station. The power supply output is then connected to a littelfuse of 25A. The fuse is close to 10 cm away from the Anderson connector which connects to the tether. A 24V fan is powered from the extension cord and it is placed on the control box to account for the heat accumulated from the power supply. The router used to connect the Raspberry Pi and the laptop used for sending commands is also located in the surface station where two ethernet cables are connected to. One cable is connected to the laptop and one is connected to an ethernet cable on the tether. The surface station contains a flat laxsand surface that separates the electronic cables to the operator of the surface station. On top of the laxsand, there is the laptop and joysticks used for operating the

WUROV. A handle on the side of the surface station is used to clip the tether for strain relief.

Figure 10: Surface side connection with a fuse to provide protection

b. Vehicle Side

On the vehicular side of the tether we understood that we needed to implement a stress relief system alongside the tether in order to prevent the weight of the tether for safety precautions as well as to not impair the movement or integrity of the ROV. We overcame this by setting up a carabiner that anchors to our on surface control station and follows the tether to the next carabiner point located on the aluminum frame of the ROV. 48V is carried through the tether and connected into the ROV via a Blue Robotics threaded waterproof connector. Each threaded connector contains a rubber O-ring that we ensure is maintained and checked prior to launch.



Figures 11 and 12: Submerged end of the tether

D. Software

1. Network Architecture

WUROV utilizes a network architecture to communicate between a control station and the operating vehicle. It is made up of three subsystems: raspberry pi, router, and laptop. These three subsystems are configured as hosts. The raspberry pi is the main address where the operating vehicle is controlled by. All commands are sent to the raspberry pi to create a path for the signals to switch components as needed. The router acts as a communication port between the control station (laptop) and the raspberry pi. The laptop is the master where all calculations and decisions are done. Algorithms and data systems determine what command has to be sent to the raspberry pi to complete a specific task such as maneuvering left, right, closing or opening gripper, or receiving pixel data from the camera.

2. Linux System Administration

The framework utilized to control the WUROV is through a linux environment under the debian distribution, Ubuntu 20.04 version. The main set of libraries for WUROV are using the first version of ROS or Robot Operating System. ROS is used to connect a set of nodes with different functions that allow the whole system to operate. The software team has been able to work in a timely manner by numerous people working together on the whole system through each member working on a different sub system of the WUROV through splitting their functionalities into their respective nodes. These nodes are made up of publishers and subscribers that are able to send or receive messages between one another. ROS also allows a host to be configured as a master core where all heavy duty calculations are to be completed. This is necessary for this case as the least amount of memory used in the raspberry pi to control the robot the more efficient the system is.

3. Software Language Rationale

Python is the main programming language used. ROS allows a number of programming languages to talk together to control different sets of nodes. Due to our network architecture, python has been the best choice due to its quick interconnection of hosts and large set of open-source libraries in robotics and image recognition software. The python community is also large enough to include numerous debugging methods and a gigantic database of errors and solutions in its forums that has assisted the software team tremendously throughout the coding experience.

E. Gripper

1. Design Iteration Process

As we started to prepare our ROV for this years' tasks, we decided that a manipulator device was needed. The team set out to accomplish this by brainstorming multiple ways that the manipulator tasks could be completed. From there, 3D models and drawings were made for each design. All of our designs were fairly similar, consisting of a pincer-like gripper using servo motors to control the motion. The team then sought out inspiration from industry methods and past WUROV designs. In our research, we found that products from blue robotics and other examples used simplistic pincers like ours. Additionally, digging through old ROV parts from past team members we came across two, well thought out and manufactured designs. Lastly, we tested the various designs that we had and selected a final design to focus on constructing.

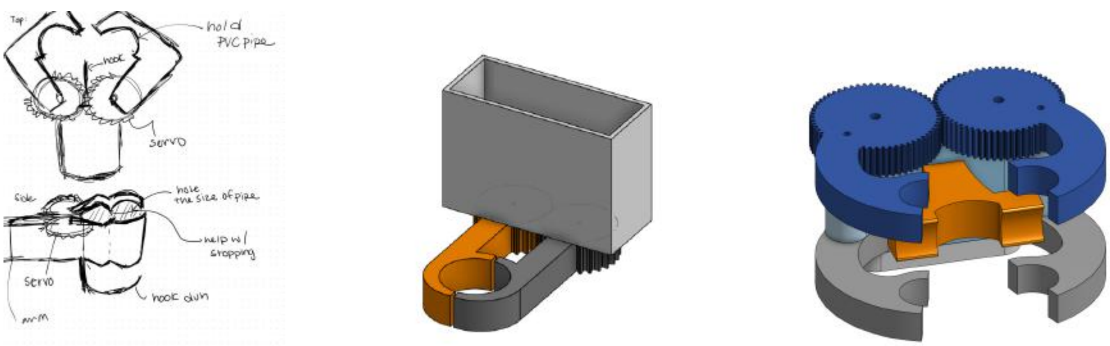


Figure 13: Early Gripper Designs

2. Final implementation

Our final design for the manipulator module involves two arms with identical grippers one axis of motion. The gripper for each arm consists of three aluminum pieces held together by screws, a servo motor, and a PLA claw piece.

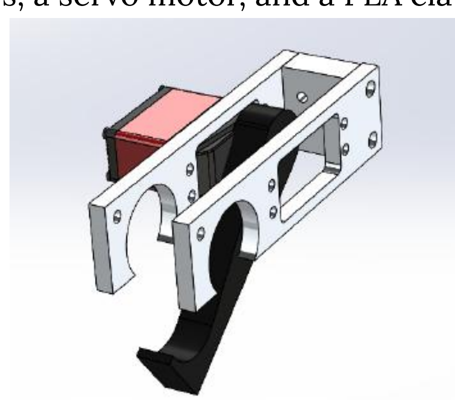


Figure 14: Final Gripper Design

The three aluminum parts are two side pieces and one middle piece connecting both sides at their ends. These side pieces have an arc shaped hole in them at the end and cut outs designed to mount the servo motor in the middle. When the servo is mounted to the gripper the claw piece fits onto the servo arm attachment and is able to move freely between both side pieces. The claw piece is designed with a rounded end in the opposite direction of the side piece arcs, guaranteeing any object to be held firmly. When an object passes through the arcs of both side pieces, the claw is moved by the motor towards the object and pushes it against the side pieces in a pincer-like motion. A joint for rotation is attached by screws to the inner face of the middle gripper piece. This joint is made of PLA and contains a slot for the rotating servo arm to fit into tightly. The servo is attached to a 5 inch long T-slot extruded aluminum rod via a PLA mount, being screwed through the square holes and secured by nuts.

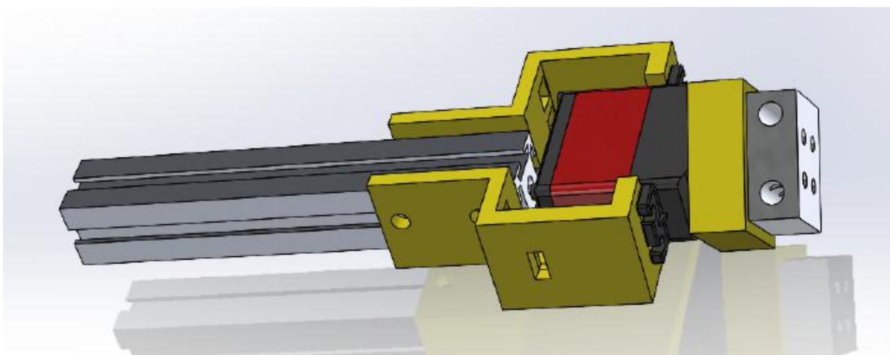


Figure 15: Gripper Rotation Joint

The mount has a slot in the side for wiring and six screw holes for fastening the mount to the aluminum. The 5 in. horizontal aluminum is connected to a 4 in. vertical piece of a similar aluminum rod using two PLA connectors.

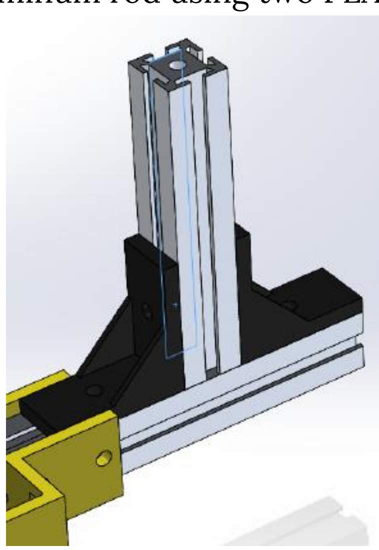


Figure 16: Arm Connectors

At the top of the vertical aluminum the mount for the ROV frame is attached. Lastly the front of the Arm-to-ROV mount is placed on the frame of the ROV and screwed into the rear of the Arm-to-ROV mount which includes a place for our camera to be mounted over the arm.

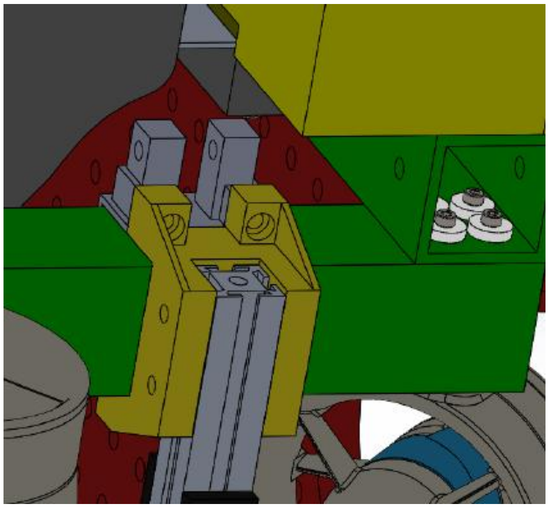


Figure 17: Arm-to-ROV mount

III. Safety

A. Company Safety Philosophy

At WUROV, prioritizing safety and well-being of members and others is the first priority. To ensure the safety of employees, everyone is required to follow the IEEE WIT Student Chapter's safety rules around the lab equipment and as well as following the MATE ROV Competition Safety Inspection guidelines when operating with the ROV. By following all the guidelines, WUROV believes accidents can be prevented when working or operating on the ROV.

B. Lab Protocols

To ensure a safe and clean work environment, all employees at WUROV are required to follow lab safety procedures. Such as wearing proper safety gear whenever an employee is working with a material that could potentially be dangerous to themselves or others. As well as requiring all employees to clean up their work area after completing their work, as to prevent any accidents or issues from happening in the future.

C. Vehicle Safety Features

Before and after using the ROV, employees are required to check if the ROV passes all the safety requirements. Please refer to Section D for the Safety Checklist that all employees must follow.

WUROV incorporates a multitude of safety measures designed to ensure the safety of individuals and the work environment. Firstly, the system is equipped with an emergency button that promptly halts all power supply to both the control system and the ROV. Additionally, the control system is fortified with a 25 amp fuse, further bolstering its protective capabilities. Furthermore, both the ROV and control system are furnished with strain relief, serving as an additional safety feature to remove the robot from the pool incase of emergencies.

D. Operational and Safety Checklist

WUROV employees are required to follow these safety procedures before and after the operation or working on the ROV:

1. Safety Gear

- Do not have loose hair or jewelry when operating the machinery.
- Wear required and proper safety equipment for certain machinery.
- Ensure there is a fire extinguisher nearby the ROV at times when the ROV is powered.

2. Checklist Before the Operation of the ROV

- Make sure all the equipment to operate the ROV is accounted for by keeping count and track of all equipment that were put on the operation zone.
- Ensure there is a fire extinguisher nearby ROV at all times of operation.
- Ensure the electronics enclosure is tightly sealed by using a vacuum pump until an atmospheric pressure of 15 mm hg is held constant for 5 minutes.
- Insert the housing plug as fast as possible when removing the vacuum pump.
- Connect the power and ethernet cables of the tether into the electronics housing as tight as possible.
- Ensure the strain relief is properly installed with the carabiners in both ends, top and bottom side of the tether.

3. Checklist After the Operation of the ROV

- Make sure all the equipment that was on the operation zone was picked up and cleaned up before leaving the zone.
- Towel dry the ROV to remove excess water from its surface area during transportation.

- Unscrew the safety locks of the power and ethernet cables from the electronic housing.
- Remove the tether strain relief from the top and bottom side of the tether.
- Roll the tether neatly using the over-under method and store away for transportation.

IV. Logistics

A. Project Management

WUROV operates around the fundamental belief that a successful final product is dependent on streamlined communication between all team members, along with clear organization from the top down the line. The company utilizes a communication platform called "Discord" in order to keep conversations organized. Company-wide meetings are held weekly in order to keep employees up to date on department-specific progress.

B. Company Organization

The company structure is broken down into three subsystems: electrical, mechanical, and software. Due to a smaller group of students, the structure has been a work in progress. Each subsystem is broken down into team members who are reporting to a team leader. The team leaders of the subsystems have meetings every week to make decisions on the design of the ROV. The team leaders have been keeping track of attendance of the members of their team with weekly meetings to discuss the engineering process from brainstorm to prototypes, to final design. The team has been able to play to the strengths of all members and help each other in every step of the way.

C. Collaborative Workspace

We held weekly meetings to work on discussing the project both logistics and actual design, prototype, and implement design changes and features. There were also portions of some of these meetings set aside to bring everybody up to speed and get on the same page as well as give short progress reports occasionally. We also laid out tasks and challenges and then brainstormed solutions as a group then delegated tasks to people to work on. The use of the white board for conceptualizing possible solutions to challenges we faced.

D. Budget and Project Cost

The budgeting breakdown relies heavily on spreadsheets containing purchases of materials and pcb boards from 2020 having large amounts of assorted parts from previous ROVs. The cost breakdowns are broken down into categories for each of the modules (Sensor Module, Power conversion, Esc Control) electrical components, and then the frame and motors as well as waterproof enclosure.

Table 1: Cost breakdown of WUROV

Sub Project	Total Cost (USD)
Sensor Board	$587.69
Power Conversion Board	$343.89
ESC Board	$275.80
Chassis	$1,973.68
Surface Station	$489.63
TOTAL COST	$3,670.69

V. Conclusions

In conclusion, the Wentworth Underwater Remotely Operated Vehicle (WUROV) is an aquatic remotely operated robot that has the ability to receive and transmit commands and data via a tether, and using ballast tanks and weights, can be fine tuned to maintain a neutral buoyancy. The ROV is able to travel along the X,Y, and Z axis using directional thruster motors. The thrusters can also manipulate the yaw while the weight balancing system manipulates the pitch. The ROV is equipped with a robotic arm that is able to rotate and grab onto objects under water. It has a light and a digital camera that feeds back to the control station for clear video underwater. The ability to grab and manipulate objects, combined with its own ability to maneuver and manipulate position makes the ROV an optimal underwater multi-purpose tool to complete various missions and tasks that cannot be done by man.

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