WooWave 2024 Technical Paper

Larissa Meyer, Aditri Thakur, Henry Wagg, Christopher Adzima, Evan Seki,Grace Amlicke, Dilce Oliveira, Hudson Kortus, Steven Voscko, Arshia Balaji, & Ahmed Salih

***Abstract*—WooWave is a rookie team from Worcester Polytechnic Institute, officially formed in January of this past year. This past season saw the administrative development of the team with a strong focus on education and research for members to be introduced to underwater robotics. WooWave's primary goal for the 2024 season is to build a technical and administrative framework for future years, as well as develop resources that can be used for future AUV development. The team is excited to attend the Robosub 2024 competition as a learning experience to further prepare for upcoming seasons.**

I. Introduction

WooWave was founded in January 2024 by a small group of ambitious engineering majors at Worcester Polytechnic Institute. The team is made up of twelve undergraduate members from diverse engineering disciplines (Mechanical Engineering, Robotics Engineering, and Computer Science). For this first season, the team prioritized establishing an executive board with administrative responsibilities, developing relationships with potential sponsors and school facilities, and fostering the growth of a supportive team community. Our team aims to build a space where students are not afraid to ask questions and learn. This year, WooWavereally wanted to focus on creating new and innovative solutions to the obstacles presented at competition, with the goal of utilizing softer materials when creating our system. The field of soft robotics has major implications within AUVs and other underwater robots, and presents a unique challenge to our team members. As a new team, we recognize the unique opportunity we have to chart new paths and bring fresh ideas to competition and look forward to doing so.

II. Competition Strategy

For the Robosub 2024 Competition, WooWave focused on establishing a team presence at Worcester Polytechnic Institute and educating its members on the many components needed to construct an Autonomous Underwater Vehicle. The team developed faculty relationships as well as preliminary sponsor relationships. Additionally, WooWave was able to find a facility on campus that will serve as a lab space for upcoming competition seasons. By concentrating on building a social, financial, and educational foundation for the team, we believe that we can put future members in a position to succeed.

This year, the members of WooWave opted to not form official subteams. Instead, the team focused on using the competition tasks to familiarize members with all aspects of Robosub. Students were encouraged to step out of their areas of expertise and research AUV components outside of their disciplines. Through this process, our students were able to expand their knowledge base and develop a collection of technical resources that will be used in future years. WooWave believes that this approach will allow members to face future seasons with a well-rounded perspective and deeper understanding of how the subsystems of the sub interact.

Despite not entering a sub for the 2024 Robosub competition, the members of WooWave still went through the process of game analysis to determine what would be considered a hypothetical MVP (Minimum Viable Product). Members were divided into three subteams with focuses on the different competition elements (Coin-Flip, Gate, Buoy, etc), and challenged with presenting technical solutions by using past Robosub documentation as well as personal research. To evaluate the robustness of the presented technical solutions, the team practiced SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis. Using the information presented by each of these subteams, WooWave decided that the MVP threshold would include navigating through the gate, circumventing the buoy, and placing at least two of the samples in the octagon.

III. Design Strategy

While WooWave did not develop a complete sub design for the 2024 Competition, there were certain design challenges that the team decided to focus on. These design challenges include developing a robot frame, object manipulation method, and object-identifying algorithm. WooWave selected these design challenges because of their consistent application throughout Robosub competitions. The objective is to integrate the following design strategies into future robots.

A. Mechanical Design Strategy

1) Frame and Hull: The members of WooWave decided that the most effective and straight-forward way to construct the sub as a rookie team would be to use Commercial Off The Shelf (COTS) components in place of completely custom parts. The team planned to use commercial extruded aluminum in addition to Blue Robotics Thrusters and Acrylic Hull. To optimize mobility and streamline frame design, it was decided that the team would adhere to an eight thruster orientation with four vertical thrusters and four vectored thrusters (similar to the Blue Robotics Heavy Kit configuration).

2) Robotic Arm: Inspired by the Open Manipulator X (RMX52), the team set out to build a 4-degree-of-freedom robotic arm. One of the advantages of deriving the robot arm from the Open Manipulator X was the use of the Dynamixel X430 W530-R servos, however as these servos are not waterproof, the team was tasked with designing and manufacturing waterproof casings for each individual servo.

The complex geometry of the X430 servos added an extra challenge for standard waterproofing methods such as epoxy coating and oil filling, which made sealing the servo motors themselves a risky and potentially costly task. Instead, we shifted our objective towards creating an external barrier from the servos from the outside water. Each casing consists of three distinct parts: the lid, servo horn extension, and casing body.

The body was designed to conform to the unique shape of the Dynamixel X430-W350-R servos and was fitted with chamfers that help the servo slide into the casing and remain in place. The ridges inside of each casing were sanded down to achieve the correct tolerances for each servo. Filets were used to allow for easy installation of the servos and to mitigate the tearing of o-rings during the installation process. The body also has through holes to allow for screws to be inserted for added protection. The lid has a channel for wires to be inserted through and was designed to hold a 608 bearing to assist in the integration with the robotic arm links. Inspired by the waterproofing methods used by Blue Robotics in their BlueROV2, the servo casings were also designed to use custom-fit O-rings to provide a water-tight seal. Both the servo horn and lid had two layers of O-rings which were covered in grease to form a water-tight seal.

The nature of an underwater robotic arm necessitates a specialized design to mitigate the effects of its intended environment. The arm must be strong enough to function continuously without breaking, but light enough that the movement of the arm does not significantly change the center of gravity or inertia of the entire robotic system. Three main factors influence the design of the arm: viscosity of the environment, chemical properties of salt water, and how the fabrication method affects the structure of the arm.

The viscosity of water plays a role during the motion of the arm. Since water has a higher viscosity than air, measures must be taken to reduce the resistance of motion from the arm. For our application, this meant reducing the drag that the water imposed. To achieve this, we skeletonized each of the links to maintain the strength, while reducing surface area and allowing water to flow through the links. This reduced the effects of the arm's movements on the rest of the robot. Skeletonization of the links also helps with the geometric strength of the part. Using this technique, the footprint of the part can be larger while using the same material, meaning that the profile of the part can take up a larger area. This same principle, in addition to other geometric structures, helps reduce the flex of the arm, decreasing the potential backlash imposed with long linkages.

3) Soft Gripper: Soft grippers are becoming increasingly popular for use in underwater manipulation due to their versatility and ability to hold delicate specimens. As a design strategy to manipulate the samples for this year's competition, WooWave decided to implement a soft fin-style gripper. This design utilizes the soft robotics concept of "intelligent materials" as a method of using soft materials in place of complex actuation systems. To prototype this gripper design, we printed it with flexible TPU (thermoplastic polyurethane). This allows the gripper to bend around a great variety of shapes, enabling the hypothetical AUV to interact with all three samples in this years' challenge. The gripper is actuated by a screw-system attached to a continuously rotating servo.

B. Software Design Strategy

WooWave decided to implement YOLO v5, a convolutional neural network (CNN) used for object detection. After evaluating different versions of YOLO, it was decided that version 5 best suited our purposes due to its reliability. This machine learning model would be used in conjunction with a Zed2i camera to identify objects such as the gate and potentially path markers. The team plans to implement and test the YOLO v5 algorithm on the camera before Robosub 2024 in order to provide an object detection basis for future years.

C. Electrical Design Strategy

The arm's servos are connected in series. Connected using custom length Blue Robotics marine grade wire to fit the specific lengths of the arms and hand-crimped to fit JST EHR-3 connectors. This created a simple, yet effective, way to control each servo with a streamlined interface. This means that the entire arm can be controlled through a single wire that attaches the base servo to a single USB port located on the Raspberry Pi that is already used to control the movement of the

BlueROV2. There is an inline adapter, known as the Dynamixel U2D2, that injects power from the battery and converts the signal from the USB connection to a serial connection that the Dynamixel servos require. This adapter utilizes the same voltage as the battery supplies, allowing for a simple and reliable connection. The wire that connects the base servo to the U2D2 module. Figure 5.2 shows a rendering of the fully-integrated robotic system.

Testing

1) The Arm: The arm was to be tested and used in both saltwater and chlorinated water. Both of these environments are solvents that have the potential to degrade plastics. Additionally, we needed a material that was stiff, resilient to impacts, and allowed for rapid prototyping. We chose to use PETG filament for FDM printing for quick, yet durable and chemically resistant parts. This resulted in parts that could be rapidly developed, tested, and with little cost associated with manufacturing.

Numerous small improvements were made to enhance the usability of the arm, alongside the integration of servo casings. Slots were added to the frame of the arm to allow for numerous cable tie attachment points along the links. This helps protect the cables from abrasion and snagging. Furthermore, bearing adapters are added as part of the attachment method to the servo casings. These are press-fit slots that allow for the link to attach with high stability to the casings with the use of a 608 bearing. The case is clamped between this attachment, and a second attachment plate that screws into the arm, as well as meshes with the servo horn extension.

2) The Servo Casings: The primary criterion was to ensure the casings were watertight. This metric was heavily reliant on the fabrication method and material choices. Due to time and budget constraints, the casings needed to be fabricated in a cost- and time-efficient manner that allowed the testing and production process to be easily repeatable.

A second consideration was the weight of the casings. As this arm is to be mounted to the bottom of an ROV, we had to be concerned with weight to avoid additional strain on the robot's thrusters, reducing battery life and maneuverability. Weight also plays a role in recovery from instability. If the arm adds too much weight, buoyancy will be affected, potentially rendering the robot negatively buoyant in the case of a mechanical failure.

The rigidity of the enclosure also needed to be taken into consideration. For the enclosure to seal, the flex of the material needs to be minimal to give the O-rings the best chance to seal. The rigidity of the material directly impacts the performance of the arm, increasing "slop" in the joints as the part becomes less rigid.

In our iterations of testing, we considered fabrication via Fused Deposition Modeling (FDM 3D) printing, Stereolithography (SLA) 3D printing, and CNC milling of various materials such as nylon, aluminum, and stainless steel billets. The casings went through a total of nine different FDM & SLA 3D printed iterations as outlined in the table below.

For the majority of the testing period, the cases appeared to be sealed and no visible air bubbles could be seen from the surface. At the 28-minute mark air bubbles began to surround the cases and they were pulled back to the surface to assess their performance. Neither case had succeeded as both of their materials were too porous. These tests solidified that FDM printing would not be a viable option for the final housing fabrication.

We intended for final fabrication methods to be switched to CNC milling aluminum, as the material would be waterproof, but due to restraints in the cost associated with material sourcing, fabrication outsourcing, and lead time, we chose to fabricate via SLA printing. The first SLA prototype was successful in remaining watertight after its first water test; however, the tolerances needed to be adjusted to account for the printer's alignment to fit the servos correctly.

The final casings were SLA printed using a Formlabs Form 3L printer. After the first round of casings were printed, they were ultimately unable to fit the servos due to slight tolerancing issues. The casings needed a very tight fit to remain waterproof, and thus even the slightest variation would make it difficult to fit the casings properly. When the casings were printed for the next iteration, there were unforeseen issues with the printers. The next several rounds of prints were not able to be printed securely. Some casings had holes on the side panels, the flat surfaces had curves and various inexplicable bumps or misshaping, and the inside collapsed onto itself during the printing process. It was unclear what was causing these issues as the first run of the prints seemed to print without issue. The first printer was declared broken, and went through many different repair tactics. The printer was cleaned, recalibrated, and had its resin completely recycled, but none of these attempts proved successful in returning the printer to its original state. For the final presentation of the project, the casings were FDM printed using a Prusa MK3 to allow for the final version of the arm to the robot.

Acknowledgments

We would like to extend our gratitude to Dr. Markus Nemitz who served as our faculty advisor for this past season. Without his support, our goal of founding this team would not have been possible. WooWave would also like to thank Worcester Polytechnic Institute for its financial assistance, as well as Mathworks for being our first sponsor.