Washington State Universities' Palouse RoboSub: Technical Design Report

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***Abstract*- The Palouse RoboSub team is a student organization at Washington State University. The club consists of undergraduate students across mechanical engineering, computer science, and electrical engineering. The team's main autonomous underwater vehicle, Cobalt, has been under continuous development for several years and has competed in multiple RoboSub competitions in various forms. The current focus of the team is the development of a secondary AUV as well as further improvements to Cobalt. The goal is to establish a pair of communicating, uniquely configured vehicles. Each vehicle design focusses on specialization in a unique subset of competition tasks, while being capable of cooperative behavior where necessary. Cobalt represents the first vehicle in this pair, and the as-of-yet unnamed vehicle under construction is the second.**

II. Competition Strategy

Palouse RoboSubs' primary focus throughout the 2020 and 2021 academic years has been the development of new AUV and acoustic communication systems. The goal is to produce a low-cost, small-scale, and highly reconfigurable vehicle that can perform tasks alongside Cobalt. The first iteration of this vehicle should be sufficiently maneuverable and possess vision systems. These abilities should be sufficient for navigation tasks such as the gate and buoys tasks. The design also facilities the attachment of an additional task-oriented module such as a gripper, hydrophone array, or torpedo launcher that can perform aspects of the bins, octagon, or torpedo tasks, respectively. The module that will ultimately be equipped for competition will depend on the performance of the completed vehicle in our tests.

Cobalt has seen several hardware, software, and mechanical upgrades in recent work to improve performance at competition. Multiple electrical boards, including those dealing with thruster control and depth measurement, have been replaced with custom boards designed by the electrical sub team that address shortcomings of the prior versions. The inertial measurement unit was replaced with a newer model and mounted in a separate container, away from the electromagnetic fields generated by the thrusters, in response to notable yaw-drift during testing. Hydrophone work has been expanded with a better mounting platform for the four-piece array and refined algorithms for localizing pings. Work is also being carried out to improve the vision system with newly trained models. Despite recent failures of some of the aging componentry, the team's current strategy relies upon performing improvements to this vehicle and so its continuous operation is vital. Several repairs and modernizations have been carried out, including the repair of a damaged camera cable, hydrophone modem, and thruster control system in addition to minor electrical components, O-ring seals and 3D-printed parts. The software has also been upgraded to utilize Python3 and ROS2 by our computer science sub team.

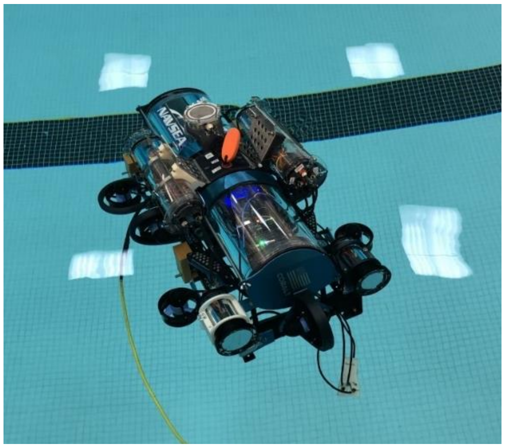

Figure 1: Cobalt at a January 2020 test

Beyond the development of vehicles, a major aspect of the teams' competition strategy and ongoing efforts is dedicated to the recruitment of new members. During recent times, student clubs such as our own have struggled to replace graduating members with incoming freshmen. The inability to meet face-to-face, access our university laboratory, or represent our club at events has limited our outreach and reduced participation interest. The clubs' strategy has been to host weekly virtual meetings where our members can socialize, collaborate on their project assignments, and learn skills from one another. The initiative has been successful in maintaining our membership and engineering progress, and our members have gained knowledge in topics such as PCB design, SolidWorks modeling, and programming.

III. Design Creativity

A. New Vehicle

The emphasis of the teams' recent design work has been in the production of our newest vehicle, for which the design goals were to be low-cost, and highly reconfigurable. These goals reflected the teams' current funding levels, and intention that the vehicle be an adaptable resource for the team as Cobalt has been. An added goal was for the vehicle to be small scale to take advantage weight of scoring bonuses and meet the competition volumetric requirements. In addition to these goals are the operational requirements of a competition-capable vehicle: ample watertight compartment space for computing boards and power systems, maneuverability through a 3D space, and frame mounting positions for exterior sensors and thrusters. Finally, there are the safety requirements for vehicles that are found in the RoboNation-RoboSub mission and scoring guidelines. In line with these goals, initial frame designs were produced with imposed limits of one main electronics vessel, four thrusters, a minimal framing structure and reliance on 3D-printing and off-the-shelf components as much as possible.

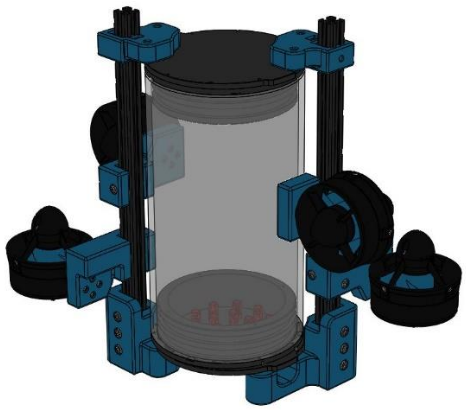

Figure 2: CAD render of the new vehicle frame

The team arrived at an upright cylinder design with two differential-steering forward thrusters and two dive thrusters. The unconventional form provides large vertical separation between buoyancy and gravity centers by concentrating heavy componentry near the bottom, and foam (not pictured) near the top of the vehicle. This separation of buoyancy and gravity centers produces a strong righting-moment in both roll and pitch to address instability that could not be counteracted by two dive thrusters alone. The tradeoff is a large forward-facing cross-sectional area and sensitivity to yaw. With the relatively low speed of competition vehicles and 20-minute operation cycles, however, the increased drag and subsequent power demands are an acceptable sacrifice.

The main compartment is a six-inch diameter tube that electrical component selections have been sized for. Many boards, such as those for camera interfacing and thruster control, have been custom designed by the electrical sub team with the limited available space in mind. The frame itself is constructed from aluminum tubing and 3D printed brackets, allowing for quick reconfiguration and the seamless addition of modules. Cables pass through penetrators in the bottom plate, while the upper plate is reserved for accessibility and the kill-switch system. The acoustic system for communication is being developed around our existing hydrophone work.

B. 3D Printing

The mechanical engineering sub team regularly utilizes 3D printed components for load bearing applications both within and external to the watertight compartments on our vehicles. The manufacturing process allows for rapid prototyping and fine-tuned geometry on a sustainable budget. A notable limitation in the field of underwater vehicles, however, is an inability to produce reliably watertight prints. The internal low-density structures of 3D prints tend to flood through microscopic holes in the layered walls during submersion, and varying density and layer thickness settings does not consistently prevent this. The capability to create consistently watertight parts through 3D printing would assist in buoyancy adjustment and allow for far-greater design freedom in new vehicles.

Members of the team have been exploring solutions to this difficulty since 2019 and have found success in an electroplating process. Through developing a nickel-electroplating bath and methods for plating PLA plastics, this sub team has been successful in producing small, electroplated 3D printed vessels in mere hours. The produced vessels, once fitted with an O-ring, withstood extended periods of submersion at fifteen feet of depth without showing signs of leakage. The team is eager to regain lab access to scale up the operation and begin deploying such manufacturing techniques on our vehicles.

Figure 3: Example of a prototype 3D-printed-electroplated compartment

IV. Experimental Results

Construction of the newest vehicle has been halted since March 2020 when Palouse RoboSub lost facility access due to Covid-19 safety measures. Similarly, no testing of Cobalt has been permitted since then. The team is eager to begin building and testing our systems once again with the return of facility access this July.

Experimentation both in-water and within simulation plays an important role in the teams' design cycle. In regular times, pool sessions would be rented twice per month for testing at WSU's Gibbs Pool. Competition tasks would be evaluated by props produced by the mechanical sub team, and Cobalt would be tethered via ethernet cable to monitor performance and push quick changes. Physical testing out-of-water and simulated testing took place weekly. Both simulation and out-of-water tests are important for establishing the basic operation of a system but are no substitute for in-water testing. The team operates on an approximately 4:1 ratio between hours spent in the lab and testing at the pool. This allocation not only reflects a balance between system engineering and experimentation, but also the rental budget and time constraints of our student members. In general, the team relies on an agile design process to determine our testing needs. Systems are tested as soon as they are deemed sufficiently operable rather than late-on in the engineering process, providing immediate feedback to make changes and catch unforeseen flaws.

V. Acknowledgements

The Palouse RoboSub team would like to thank our sponsors for their generous support:

NAVSEA

WSU

Digilent

NoMachine

OSH Parks

MathWorks

Circuit Lab

The team would also like to thank our NAVSEA mentors Aaron Darnton and Daryn Bartlett, as well as our advisor Dr. Ganapati Bhat and all other WSU professors who have provided technical advice.

Appendix A.1: Component Specifications for Cobalt

Component	Vendor	Model/Type	Specs	Cost	Status
Frame	Custom				Installed
Waterproof housing	Custom, Blue Rob.		3’’ Series,		Installed
Waterproof connectors	Blue Robotics	Penetrators	6mm, 8mm	$5	Installed
Thrusters	Blue Robotics	T200 Thruster		$179	Installed
Motor control	Blue Robotics	Basic ESC	30 A	$25	Installed
High level control	OSH Park, Digi-key	Custom printed PCB’s			Installed
Actuators	Hitec	D646 32-Bit Waterproof Servo	IP-67 rated	$56	Installed
Battery	Tattu	Z160218014100006	16000mAh 14.8V, LiPo	$223	Installed
Converter, Regulator	Droking	X000Q0Z0DR	LM2596 Buck Converter	$15	Installed
CPU	Intel	NUC	Intel Core i5	$300	Installed
Internal Comm Network	Netgear	GS108	8 Port, 1 Gb network switch	$46	Installed
External Comm Interface	Subconn	Subconn Circular Series	Ethernet		Installed
IMU	x-io technologies	NGIMU		$340	Installed
Vision	Pointgrey	Fl3-GE-14S3C-C	1.4MP, 1384x1032	$895	Installed
Acoustics	Aquarian Scientific	AS-1 Hydrophone		$395	Installed

Component	Information
Algorithms: Vision	Deep Neural Network with Tensorflow
Algorithms: Acoustics	Time delay cross correlation
Algorithms: Localization and Mapping	Kalman and particle filter, point cloud
Algorithms: Autonomy	Hierarchical state machine
Open Source Software	ROS, OpenCV

Appendix A.2: Component Specifications for new vehicle

Component	Vendor	Model/Type	Specs	Cost	Status
Frame	McMaster-Carr	20mm T-slot framing	Added 3D prints	$80	Purchased
Waterproof housing	Blue Robotics	Watertight Enclosure	6’’ Series	$320	Purchased
Waterproof connectors	Blue Robotics	Penetrators	6mm, 8mm	$5	Purchased
Thrusters	Blue Robotics	T200 Thruster		$179	Purchased
Motor control	Blue Robotics	Basic ESC	30 A	$25	Purchased
High level control	OSH Park, Digi-key	Custom printed PCB’s			Purchased
Battery	Tattu	Z160218014100006	16000mAh 14.8V, LiPo	$223	Purchased
Converter, Regulator	Droking	X000Q0Z0DR	LM2596 Buck Converter	$15	Purchased
CPU	Intel	NUC	Intel Core i5	$300	Purchased

Component	Vendor	Model/Type	Specs	Cost	Status
Internal Comm Network	Netgear	GS108	8 Port, 1 Gb network switch	$46	Purchased
IMU	x-io technologies	NGIMU		$340	Purchased
Vision	Teledyne FLIR	FL3-U3-13E4C-C	1.3MP, 60 FPS	$950	Purchased
Acoustics	Aquarian Scientific	AS-1 Hydrophone		$395	Purchased

Appendix A.3: Team Information

Team Size	20
HW / SW expertise ratio	60/40
Testing Time: simulation	~100 hrs
Testing Time: in-water	N/A
Programming languages	C, C++, Python

Appendix B: Outreach Activities

Palouse RoboSub typically participates in outreach events at the local Pullman high school, Kids‘ Science and Engineering Day on WSU’s campus, and various club engagement activities for WSU students. Prior to March 2020, Palouse RoboSub also regularly hosted tours of our lab for elementary school groups, incoming freshmen, and industry visitors. With the cancellation of all in-person activities on our campus since March 2020, our club has continued outreach activities through social distancing by speaking at online meetings of freshmen classes and hosting our own information sessions. The club also participated in a crowdfunding campaign last November that spread awareness about our group.