SDSU Mechatronics 2019 AUV Vehicle: Perseverance

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ABSTRACT - Perseverance is the Mechatronics AUV for the 2019 Robosub competition. The main goal for the team was to make a modular design that would eventually be able to compete all obstacles but still let us focus on certain tasks. This strategic decision guided the design efforts, leading to a mechanical design with swappable components, a generalized electrical system capable of accepting any printed circuit board with a common interface, and ample opportunity for future expansion.

I. INTRODUCTION

Mechatronics is a student-run organization affiliated with San Diego State University(SDSU) that is composed of over 30 undergraduate student members. Over the years, we have developed four vehicles: three autonomous underwater vehicles (AUVs) and one unmanned aerial vehicle.

Our goal is to provide a hands-on learning experience to students while developing new autonomous systems. This year, we have focused on improving the system and increasing testing time for the AUV.

A. Existing Work

Mechatronics has made three AUVs: Endeavour, Defiance, and Perseverance. These previous vehicles have provided heaps of experience and information for our latest design.

The software team has carefully redesigned the software architecture to be more robust, configurable, and ultimately easier to teach to new software members. Compared to previous years, the team focused more on documentation, uniform code structure, and modular parameter configurability to standardize to development and testing process. Furthermore, the controls and computer vision systems of the vehicle have been improved by putting them through more rigorous testing.

The electrical team built off the concept of previous vehicles using a backplane, daughter cards, and a primary computer. This year we made an active backplane, or motherboard, based on the previous design.

The mechanical team also learned from the mistakes of past designs and improved upon important features in Perseverance such as modularity and accessibility. To make the AUV more expendable, we included diverse mounting points on the external and belly frame. To increase accessibility, we implemented a single clamshell seal to easily access all internal components.

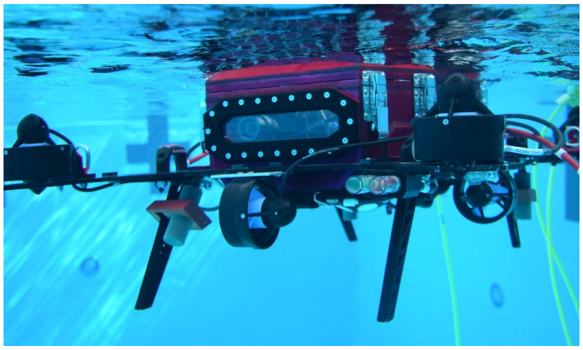


Fig. 1: Perseverance being tested at the SDSU pool.

B. New Features and Improvements

This year the software system was entirely redesigned to be more modular, readable, and maintainable. Two significant architectural improvements included are a decentralized Graphical User Interface

(GUI) and our developed socket based communication library MechOS. In previous years, the GUI was written inline with the operating system on the vehicles and command of the vehicles during testing was performed through a Virtual Network Connection (VNC). This entailed extra processing effort for the on-board computer to perform both the autonomy of the sub and controlling the GUI. The new architecture places the GUI and control of the vehicle on the users computer, while the vehicle only runs its the necessary components for control and autonomy.

The socket based communication library MechOS provides a UDP and TCP based communication protocol that enables the individual systems to be developed in a modular way. The library includes features such as a topic based publisher/subscriber protocol, a XMLRPC based parameter server, and UDP based video streaming. MechOS also allows for inter and intra based machine communication, which allows us to run process on multiple computing devices if desired.

New electrical features for the vehicle include a new primary communication protocol, CAN bus, as well as a new secondary communication protocol, I2C.

The mechanical aspects of Perseverance are a complete overhaul of previous designs. Learning from restrictions of tubular cramped enclosures, tightly toleranced radial seals, permanent cable passthroughs and asymmetric overall layout, the new design aimed to learn from these lessons. New features of the mechanical systems include implementation of pneumatics for all actuation, plate aluminum construction with minimal machining, protective modular external frame, standardized fasteners for entire design, a single main seal, swappable IO panels for all cable pass throughs and large top viewing windows.

Fig. 2: Final CAD of Perseverance

II. COMPETITION STRATEGY

Based on last years inconsistency to successfully complete any of the tasks with reliability, the competition strategy this year is to focus on consistency of completing a few tasks with high confidence rather than attempting to multi-task with low confidence.

More detailed and extensive testing was performed on the navigation system to ensure it could accurately maneuver the vehicle accurately. Given the increased performance in the control, higher level design of autonomy can be developed for completing tasks without worrying about the consistency of control. There was also a greater focus on improving the computer vision system.

III. VEHICLE DESIGN

For the overall design of the AUV vehicle and its systems, the focus was on simplicity, accessibility, and modularity. We found that focusing on these aspects made the design more efficient for testing and debugging purposes.

A. Mechanical Systems

Learning from previous vehicle designs, Perseverance incorporates a clamshell lid design along with a single main O-ring seal, created by welding watejetted aluminum panels together. This design increases the internal volume allowing a sufficient amount of space for the electrical system. The symmetrical design facilitated the buoyancy control of the AUV by keeping the center of gravity close to the center of Perseverance.

A unique design feature that the AUV includes is swappable Input-Output panels for all cable pass throughs, which make it easy to accommodate future sensors.

Another inclusion of modularity in the AUV's design is the variety of mounting points for payloads and external sensors. The main location for mounting is the external frame, which also serves as protection against impact. There is also an exterior frame at the belly of Perseverance that houses most of the pneumatic system. Both frames include mounting slots designed for our standardized fasteners.

An internal frame was redesigned this year to facilitate cable management while maintaining accessibility to internal components and maximizing space. Perseverance's large top viewing windows also make debugging easier when the AUV is undergoing underwater testing.

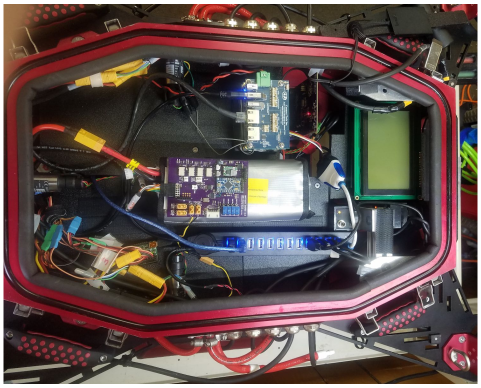


Fig. 3: Perseverance's internal components.

B. Electrical Systems

Our electrical system is made up of six custom boards designed by our members: Weapons Control Board (WCB), Sensor Interface Board (SIB), Battery Management System (BMS), Hydras, Pneumatics Interface Board (PIB), and the Motherboard. All daughter cards connect to the Motherboard through DBUS connectors, which allow us to make new boards with different functionality and capabilities, while incorporating them into the current system seamlessly.

All of our custom boards communicate via CAN Bus. We decided to use CAN because of its ability to support a large amount of devices and messages. CAN also only requires two signal lines for communication which allows for minimal wire management. The main processor, the Tegra X2, then communicates with all the boards through CAN, simplifying our interfacing with the embedded systems.

C. Software Systems

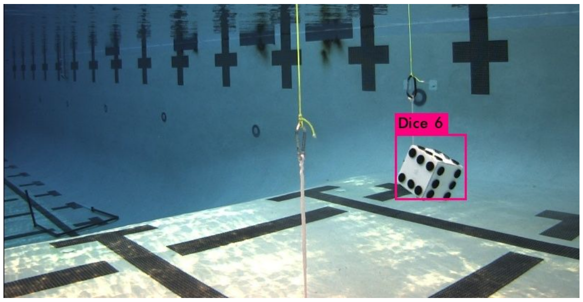


Fig. 4: Computer vision recognizing a dice for the buoy mission based on the 2018 competition.

Our software system is developed primarily in Python because of its ease of use and it is less difficult for less experienced members to learn compared to competitive other languages like C++.

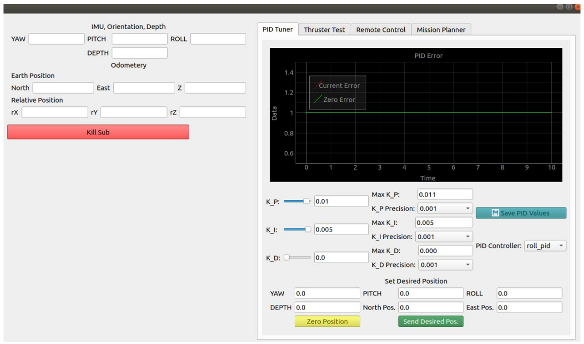
The software architecture of the system is divided into multiple separate subsystems that are highly parameterizable and easy to test. For the most part, the systems can run independently of each other.

These systems include the Sensor Driver, Navigation Controller, Mission Commander, Vision, and Main Controller. The Sensor Driver systems gather and process data from the DVL, AHRS, and pressure transducers to determine the position of the vehicle.

The Navigation Controller takes the position data provided by the Sensor Driver and uses a well-tuned 6 DOF control PID control system to navigate the vehicle to its desired position and orientation.

The Vision system runs the YOLOv3 Tiny object detection network to detect and localize objects underwater. Then an algorithm called Solve PNP is used to determine the distance and angular orientation of the object so the vehicle can best learn the orientation and distance necessary to reach its desired object. The vision system also live streams the video over UDP to get real time footage.

The Mission Commander is a higher level system that executes mission objectives specified in a mission file by communicating with the lower level systems. This mission file is generated with the Mission Planner widget in the GUI.



K_P: 0.01
Max K_P: 0.011
K_P Precision: 0.001
K_I: 0.005
Max K_I: 0.005
K_I Precision: 0.001
K_D: 0.0
Max K_D: 0.000
K_D Precision: 0.001
PID Controller: roll_pid
YAW 0.0
PITCH 0.0
ROLL 0.0
DEPTH 0.0
North Pos. 0.0
East Pos. 0.0

Fig. 5: The GUI for the RoboSub competition.

IV. EXPERIMENTAL RESULTS

This year, due to technical challenges, we achieved less testing than desired. However, more rigorous testing procedures for the software systems were employed to ensure we maximize the testing time available. First, we focused on tuning and testing the PID control system to ensure the vehicles stability and ability to hold desired positions.

The Proportional-Integral-Derivative (PID) controller is a feedback control loop that determines a control parameter (such as thrust) given error between a current position and desired position. The vehicle contains six PID controllers to control each degree of freedom: roll, pitch, yaw, X (forward/backward), Y (strafe Left/Right), and depth. First, the depth controller was tuned. In tunning depth, we achieved better stability compared to previous years by applying a depth activated bias in the Proportional controller that would make the sub mimic being neutrally buoyant instead of positively buoyant. As a result, less power is consumed because the thrusters no longer switch directions at a high frequency.

After the PIDs had been tuned, we focused on collecting waypoints, developing the mission architecture, and labeling images of obstacles to begin focusing on missions.

We are currently in the process of training the computer vision system and testing waypoint navigation to perform the gate and buoy missions.

In order to test our electrical system, we have designed an "electronics test-fixture". This test-fixture allows our electrical members to program and test their custom PCBs outside of the vehicle. By having a test-fixture, we can quickly identify bugs with the embedded code or with the circuit design. In previous years, the PCBs had to be tested directly in the AUV which made it very difficult to find the sources of issues.

Additionally, we confirm watertight integrity of the AUV by performing a vacuum d vacuum test each time seals are broken on the vehicle.

IV. ACKNOWLEDGMENTS

The Mechatronics team would like to thank the SDSU Engineering Department, Northrop Grumman, Matlab, Metal Masters, Amazon, McMaster-Carr, and Altium.

A big thank you especially to our faculty advisor Theresa Garcia, as well as Donovan Geiger and the late Dean Mehrabadi who always supported and believed in us.

VI. REFERENCES

[1] J. Redmon and A. Farhadi, *YOLOv3: An Incremental Improvement*. Washington: University of Washington, 2018.

Appendix A: Expectations

Subjective Measures			
	Max Points	**Expected Points**	**Points Score d**
Utility of team website	50	45	
Technical merit (from journal paper)	150	120	
Written style (from journal paper)	50	40	
Capability for autonomous behavior (static)	100	80	
Creativity in systems design (static)	100	80	
Team uniform (static)	10	8	
Team video	50	40	
Pre-qualifying video	100	0	
Discretionary points (static)	40	0	
Performance Measures			
Weight	See Table 1/ Vehicle		
Marker/Torpedo over weight or size by <10%	Minus 500/ marker	0	
Gate: Pass through	100	100	
Gate: Maintain fixed heading	150	150	
Gate: Coin Flip	300	0	
Gate: Pass through 60% section	200	200	
Gate: Pass through 40% section	400	400	

Gate: Style	+200 (8x max)	200	
Collect Pickup: Crucifix, Garlic	400/object	0	
Follow the "Path" (2 total)	100/segment	100	
Slay Vampires: Any, Called	300,600	0	
Drop Garlic: Open, Closed	700, 1000 / marker (2 + pickup)	700	
Drop Garlic: Move Arm	400	0	
Stake through Heart: Open Oval, Cover Oval, Sm Heart	800, 1000, 1200 / torpedo (max 2)	0	
Stake through Heart: Move lever	400	0	
Stake through Heart: Bonus - Cover Oval, Sm Heart	500	0	
Expose to Sunlight: Surface in Area	1000	0	
Expose to Sunlight: Surface with object	400/object	0	
Expose to Sunlight: Open coffin	400	0	
Expose to Sunlight: Drop Pickup	200/ object (crucifix only)	0	
Random Pinger first task	500	0	
Random Pinger second task	1500	0	
Inter-vehicle Communication	1000	0	
Finish the mission with T minutes (whole + factional)	Tx100	0	

Appendix B: Component Specifications

Component	**Vendor**	**Model/Type**	**Specs**	**Cost(if New)**
Buoyancy Control	PVC Pods			
Frame	Custom 6061 T6 anodized aluminum, 0.25” Thickness			
Waterproof Housing	Custom 6061 T6 anodized aluminum, 0.25” and 0.5” Thickness			
Waterproof Connectors	Seacon	WET-CON		$300
Thrusters	Blue Robotics	T200		$169
Motor Control	Hobby King	Afro 30A Race Spec	30 amp	$13.69
High Level Control	NVIDIA	Jetson Tegra X2		$599
Actuators	None			
Propellers	Blue Robotics	T200		$169
Battery	Hobby King	Lipo Battery	16000 mAh 4s 10c Multistar	$101.37
Converter	None			
Regulator	Mini-Box	DCDC-USB		$54.95
CPU	NVIDIA	Jetson Tegra X2		$599
Internal Comm Network	Custom			
External Comm Interface	Seacon	Seacon Cable		$1000
Programming Language 1	Python			
Programming Language 2	C++			
Compass	Sparton	AHRS 6E		$1500

Inertial Measurement Unit (IMU)	Sparton	AHRS 6E		$1500
Doppler Velocity Log	Nortek	DVL1000		$18000
Cameras	Point Grey	BFLY-U3	Resolution: 808x608	$325
Hydrophones	Sparton	PHOD1		$999
Manipulator	None			
Algorithms: vision	You Only Look Once V3			
Algorithms: acoustics	N/A			
Algorithms: localization and mapping	DVL, AHRS			
Algorithms: autonomy	PID			
Open source software	OpenCV, PyZMQ			
Team size	32			
HW/SW expertise ratio	1.5			
Testing time: simulation	0			
Testing time: in-water	50 Hours			