Marine and Naval Technological Advancements for Robotic AutonomY (MANTA RAY)
Ghost Unpiloted Performance Platform Submersible (GUPPS)

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1. MANTA RAY Mission

Team MANTA RAY is an interdisciplinary marine robotics project focused on seafloor mapping and underwater perception. As shown in Figure 1, the project emphasizes inter-vehicle communication, autonomous behavior, and mechanical system improvements to increase precision and performance.

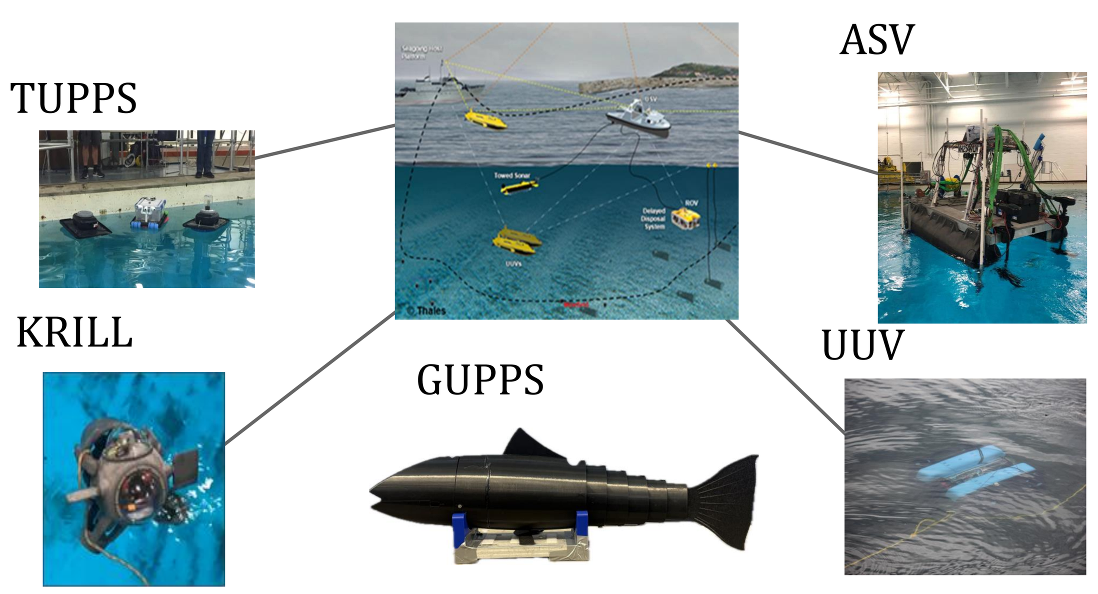

Figure 1. Overview of Team MANTA RAY mission

2. GUPPS Mission

- ❑ GUPPS is a biomimetic robotic fish designed to unobtrusively investigate underwater environments.
- ❑ GUPPS can be applicable to covert operations leveraging low-noise and low-acoustic-signature characteristics, including underwater reconnaissance, mine detection, port monitoring, and submarine tracking.
- ❑ Previous development enabled in-plane motion using a caudal fin to control movement throughout the water column.
- ❑ Current work focuses on advancing propulsion and control to support movement and improved maneuverability.
- ❑ The long-term objective is to create a coordinated “school” of GUPPS capable of autonomous, multi-vehicle operation.
- ❑ Supports grad research in wireless optical communications

3. Requirements

FUNCTIONAL REQUIREMENTS

- ❑ The system must support autonomous fin-based propulsion, enabling controlled forward motion and maneuverability using caudal and pectoral fins.
- ❑ The platform must enable Robot Operating System 2 (ROS2)-based communication to coordinate multiple subsystems and allow real-time control through a Graphical User Interface (GUI) or Proportional-Integral Derivative (PID) controller.
- ❑ GUPPS must achieve stable 5D movement, allowing control in the x, y, z axes, yaw, and pitch for realistic underwater navigation.

NON-FUNCTIONAL REQUIREMENTS

- ❑ The system must be waterproof and pressure-resistant to ensure reliable operation in underwater environments.
- ❑ The platform must maintain long-duration reliability, with components capable of sustained operation without failure.
- ❑ The design must be scalable, easy-to-assemble and inexpensive, allowing coordination of GUPPS units as a swarm.
- ❑ The system must maintain stability and buoyancy control to ensure proper orientation and consistent movement underwater.

4. Project Design

MOTOR & SERVO SELECTION

The original pectoral servo configuration was replaced with higher-torque servo motors to improve:

- ❑ Servo waterproofing
- ❑ Pectoral fin maneuverability
- ❑ Post-testing fin wear

SYSTEM DESIGN

- ❑ GUPPS uses the ROS2 robotics framework to coordinate communication between onboard control components and fin-actuation subsystems.
- ❑ A Raspberry Pi 4 running Ubuntu OS hosts the ROS2 nodes and manages message passing between the GUI / PID controller and the servo-control logic.

DEVELOPMENT & INTEGRATION

To support new servos for pectoral motion, the following changes were implemented:

- ❑ Designed servo housing and updated head (CAD redesigned)
- ❑ Reworked electronics to flexibly use either 1 or 2 pectoral servos to control both fins
- ❑ Adjusted servo control code for handling new servos

Integration of previous GUPPS prototypes and prior work:

- ❑ Consolidated circuit design and diagrams
- ❑ Simplified experimental fin control code

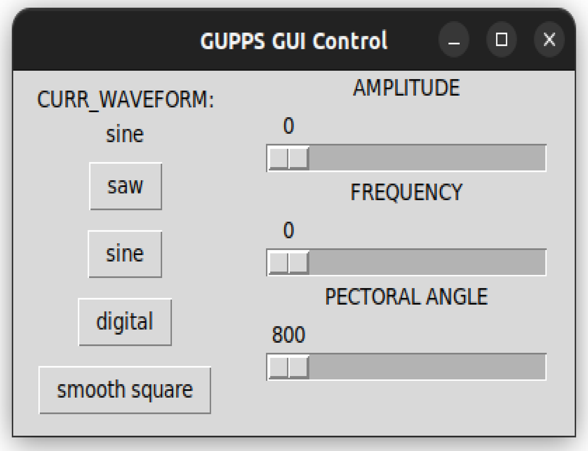

Figure 2. GUI/PID controller

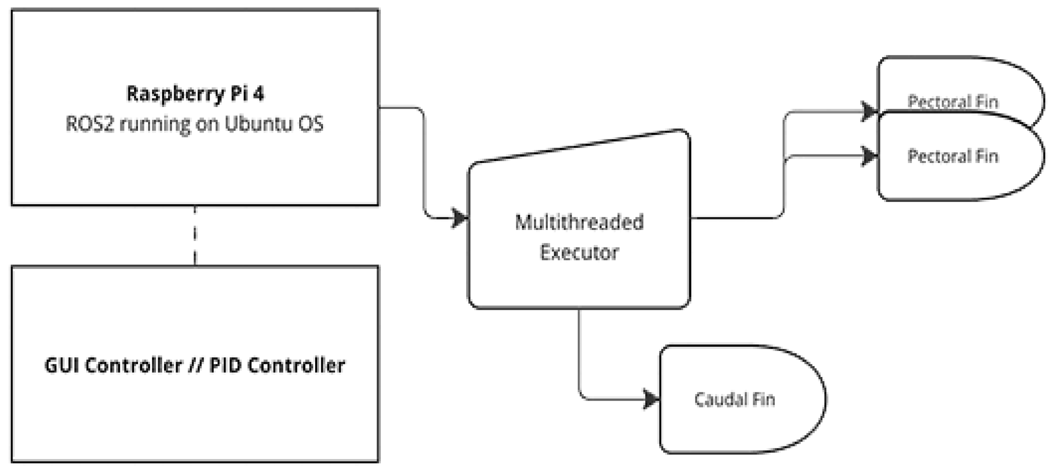

Figure 3: Subsystem diagram.

5. Hull Design and Remodeled Parts

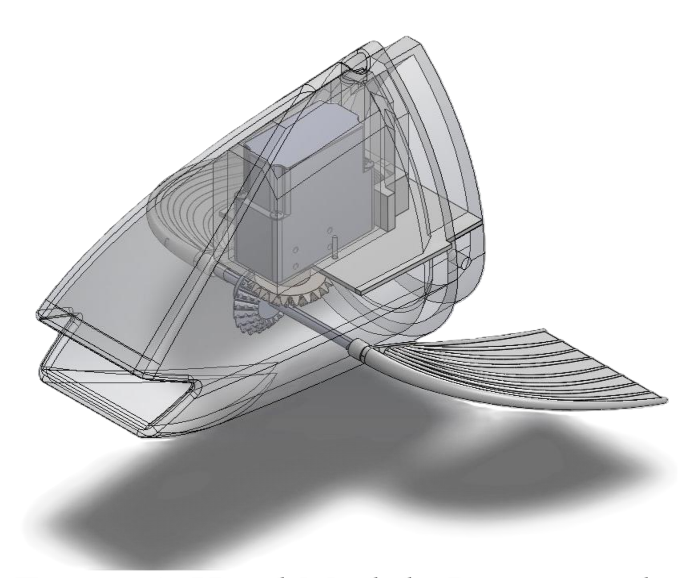

Figure 4. Head Module Design with Actuation System and Pectoral Fins

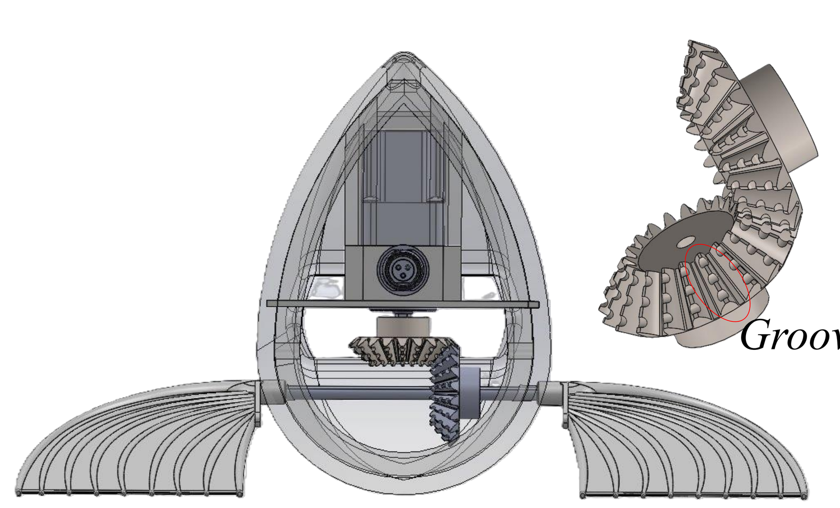

Figure 5. Head Module Design with internal parts (Top Right: Bevel gear system)

Table 1. Gear Specifications

Module	2
Number of teeth	20
Pressure angle	20°
Face Width	12mm

OVERVIEW OF THE GUPPS MODEL

- ❑ The fish is approximately 3 feet long, 10 inches tall, and 5 inches wide (without pectorals)
- ❑ The main body of the fish is 3D printed from PETG and TPU. PETG was chosen as it is the most water-resistant filament.
- ❑ The platform utilizes subcarangiform propulsion with a caudal fin for thrust and pectoral fins for maneuvering
- ❑ The fish is positively buoyant and can float on the surface of the water while mostly submerged.
- ❑ Actuated through servo-based control integrated with the ROS2 framework, which allows coordinated and autonomous operation

DESIGN CONSIDERATIONS

- ❑ Streamlined head geometry designed for subcarangiform propulsion, minimizing hydrodynamic drag and improving overall propulsion efficiency (Figure 4)
- ❑ The upgraded high-torque servo required a complete internal redesign, as the original head could not accommodate the new motor (Figure 4)
- ❑ Perpendicular orientation between motor and drive shaft was resolved using a bevel gear transmission, enabling efficient torque transfer with minimal power loss (Figure 5)
- ❑ Grooves were added above the gear tooth line to consider fluid incompressibility during underwater operation, reducing wear and heat buildup over prolonged use (Figure 5)

6. Testing

- ❑ **Bench testing** was conducted to evaluate servo performance, including response time, torque, and range of motion.
- ❑ **Waterproofing**: Submersion testing of the pressure capsule confirmed sealing for 20–30 minutes at ~0.5 m depth with no internal leakage observed.
- ❑ **ROS 2 Communication:** Verified reliable subsystem connectivity with 100% successful command transmission across repeated test cycles.

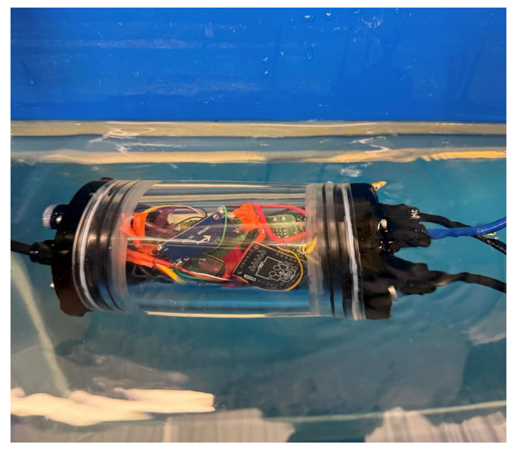

Figure 6: Waterproof Testing of GUPPS Core

7. Evaluation

Metric	Success Criteria	Results
Motion Stability	<10% trajectory deviation, no oscillation	Met: Smooth, repeatable movement achieveed
Waterproofing	No leakage at 0.5 m for 20-30 minutes	Met : No internal moisture observed
Ros 2 Communication	100% command delivery across test cycles	Met: 100 % success over repeated trials
System Modularity	Expandable code and wiring for new components	Met: ROS 2 nodes + modular wiring implementd

8. Conclusion and Future Work

CONCLUSION

The GUPPS platform integrates upgraded propulsion, a redesigned head module, ROS2-based communication, and refined control systems to enhance underwater performance. Experimental testing demonstrated stable pitch-controlled motion (1 DOF via synchronized pectoral fins), reliable subsystem communication, and faster, more responsive control behavior. These results indicate strong progress toward robust autonomous underwater operation. Successful platform duplication supports scalable multi-vehicle deployment and enables future coordinated swarm operations in underwater research environments.

FUTURE WORK

- ❑ Integrating pressure (Bar30), IMU, and sonar sensors to enhance environmental awareness and state estimation
- ❑ Improving control systems through PID tuning, closed-loop feedback, and independent fin actuation for increased DOF
- ❑ Deploying coordinated multi-vehicle swarm experiments with inter-vehicle communication in real-world aquatic environments

9. Acknowledgements

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