Human Powered Submarine Autopilot 2021

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NAVSEA NAVAL SEA SYSTEMS COMMAND KEYPORT

System Integration Engineering

Component selection:
- Pugh matrix for microcontroller and sensor solution that fit CPU, RAM, cost, complexity and dimensional requirements
- Chose Arduino Nano 33 BLE with 9 Degrees of Freedom (DoF) Inertial Measurement Unit (IMU) (*Figure 6)*

Unmanned Maritime Autonomy Architecture:
- Standardized functional framework (*Figure 4*)

Sensor Fusion:
- Accurate roll, pitch, and yaw (*Figure 5*)

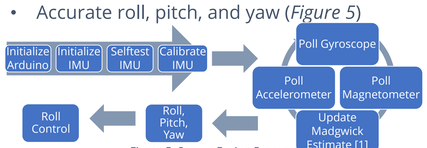


Figure 5: Sensor Fusion Process

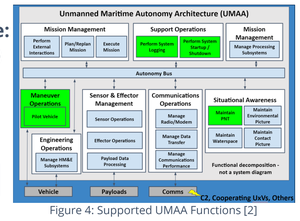


Figure 4: Supported UMAA Functions [2]

Power Engineering

- Custom PCB integrates: Arduino microcontroller, 12V DC power source, and autopilot peripherals (*Figure 6)*
- PCB features include: TPS54331 Buck ICs, Safety Fuses, Voltage Monitoring

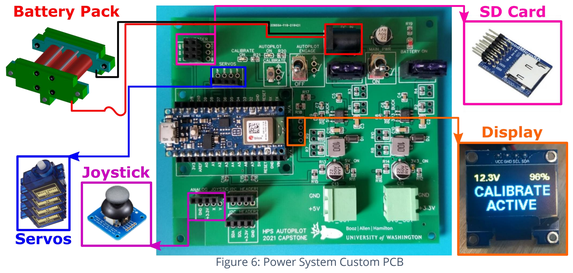


Figure 6: Power System Custom PCB

Control Engineering

Figure 7: System

Control Modeling:
- Modeled submarine roll equation
- Designed a stable PID Controller (*Figure 8*)
- Validated stability of controller gains

Hardware Implementation:
- Implemented PID controller on an Arduino
- Integrated peripheral components (*Figure 7*)

In Figure 7, above, all components of the design were integrated through Arduino. These include SD diagnostics, internal display, servo PWM, IMU sensor fusion, serial USB diagnostics, and pilot joystick passthrough.

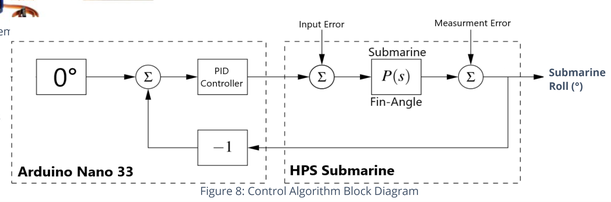


Figure 8: Control Algorithm Block Diagram

Human Powered Submarine (HPS) Summary

Background: University of Washington (UW) HPS is a student organization that races single-occupant submarines (*Figure 1*) around timed courses (*Figure 2* and *Figure 3*)

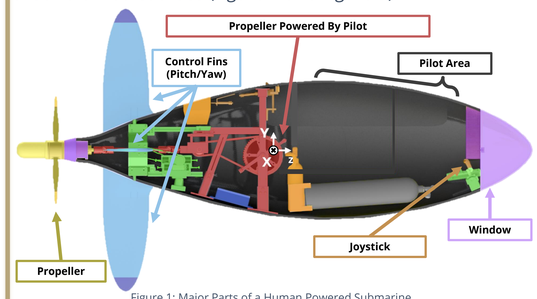


Figure 1: Major Parts of a Human Powered Submarine

Problem: Unintended roll at high velocities in races
Goal: Proportional, integral, derivative (PID) control of the submarine control fins can mitigate roll automatically

High-Level Requirements:
- Attitude and Heading Reference System (AHRS) sensing
- Modular and powered for up to 4 hours
- Automatic roll control
- Small footprint & waterproof

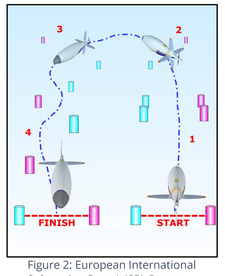


Figure 2: European International Submarine Race (eISR) Course

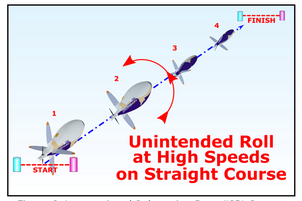
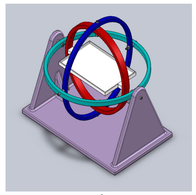


Figure 3: International Submarine Race (ISR) Course

Mechanical Design Engineering

Roll/Pitch/Yaw Validation Fixture:
- Modeled and designed 3 DoF Gimbal Prototype (*Figure 9*)
- Machined final model to use for system testing and validity (*Figure 10*)



Degree of Freedom	Ring Color
Roll	Cyan
Pitch	Blue
Yaw	Red

Figure 9: 3 DoF Gimbal design modeled in Solidworks. The roll, pitch, and yaw rings are clearly labeled in different colors.

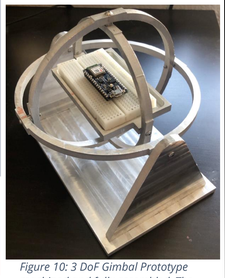


Figure 10: 3 DoF Gimbal Prototype machined and fully assembled. The Arduino 33 BLE can be seen resting on the central platform prior to testing.

Waterproof Module:
- Developed & designed final module assembly in Solidworks (*Figure 11* top-left)
- Designed & 3-D printed internal frame and mounting fixtures (*Figure 11* bottom)
- Machined multiple components necessary for physical assembly (*Figure 11* top-right)

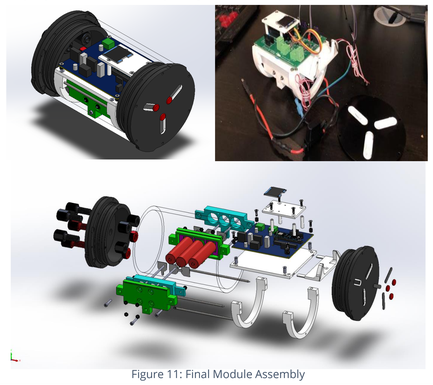


Figure 11: Final Module Assembly

HPS Autopilot Final Design

Main concept (*Figure 12 and Figure 13*) is a waterproof module that contains:
- Arduino microcontroller and IMU with sensor fusion, PID control algorithm, and embedded functionality for display, servo, joystick and data logging
- Power distribution, and peripheral component breakout board from battery power
- Waterproof enclosure with magnetic reed switches for power on/off, autopilot on/off, and autopilot calibration
- Pilot diagnostic display
- SD card diagnostic data backup

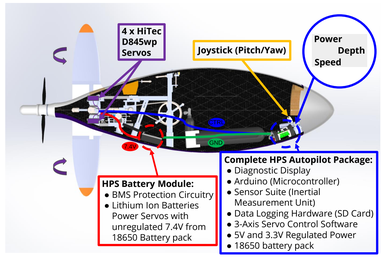


Figure 12: Initial Concept Functionality and Placement

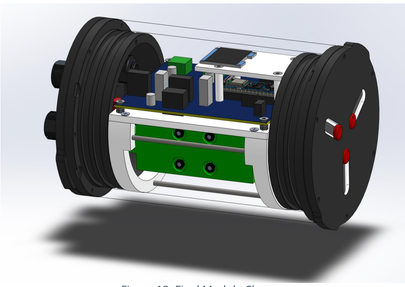


Figure 13: Final Module Closeup

Proof of Concept:
- Electronic and mechanical components were assembled to prove concept (*Figure 14*)

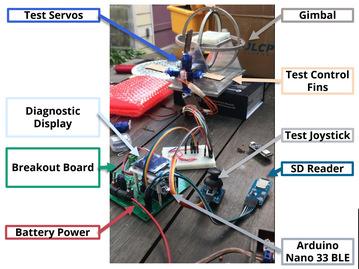


Figure 14: Proof of Concept Assembly Video

Final Assembly:
- Final assembly to ensure function and mechanical fit (*Figure 15*)

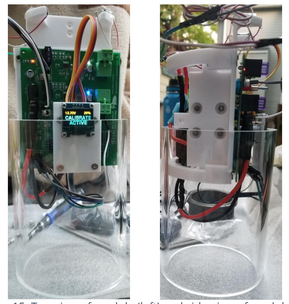


Figure 15: Top-view of module (left) and side-view of module (right)

Future Work, References, and Acknowledgments

- Additional virtual environment modeling of sensor data
- Pitch and yaw contribution to roll in control algorithm
- Mechanical fit optimization
- Integration of module into latest UW Human Powered Submarine
- Adaptation of servo-driven control fins to linear actuator-driven control fins

Industry: Eric Jones, Joe Reck, Ryan Edwards, Cooper Bowen, Jacob Yakawich
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Graduate Students: Miller Sakmar
Undergraduate Students: Chase Deitner, James Lee, Peter Tsanev

[1] S. O. H. Madgwick, A. J. L. Harrison and R. Vaidyanathan, "Estimation of IMU and MARG orientation using a gradient descent algorithm," 2011 IEEE International Conference on Rehabilitation Robotics, 2011, pp. 1-7, doi: 10.1109/ICORR.2011.5975346.
[2] United States Department of Defense. (2019, December 19). UMAA-INF-ADD. Retrieved from Defense Standardization Program: https://www.dsp.dla.mil/Portals/26/Documents/Conference/2020-StateofDSPConf_Rothgeb.pd

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