Biomimetic Seal Whisker Sensors for Enhanced Underwater Robot Navigation

Sanjay Giridharan, Aerospace Engineering
Mentor: Dr. Leixin Ma
SEMTE

Objective and Research question

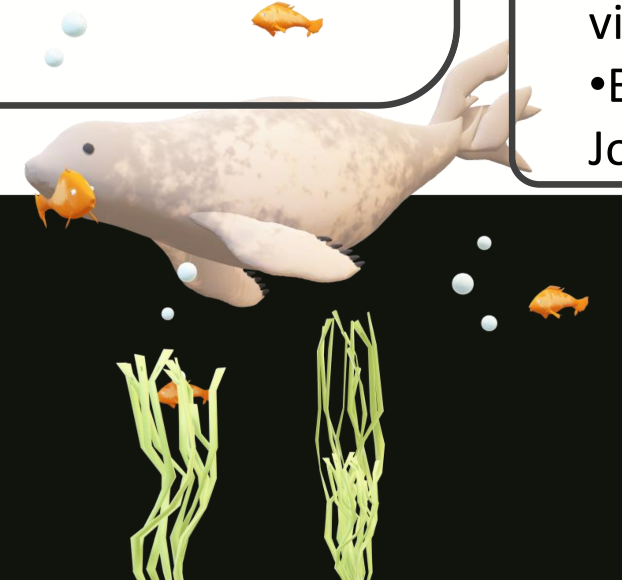
To develop and optimize nature-inspired sensors modeled after harbor seal whiskers that can revolutionize underwater robotics navigation. **Primary question:** How can the unique hydrodynamic properties of seal whiskers be engineered to maximize wake detection capabilities while minimizing self-induced noise in underwater robot sensing systems?

Research Aim

- Develop sensors that distinguish between environmental flows and self-generated movements in turbid underwater conditions
- Optimize whisker design parameters (wavelength-to-diameter ratio, cross-sectional geometry) for specific detection applications
- Balance VIV suppression with enhanced WIV sensitivity through natural frequency tuning and Strouhal number optimization
- Quantify the performance advantages over conventional cylindrical sensors

Background & Motivation

Harbor seals hunt successfully in murky waters by using their specialized whiskers to detect and follow hydrodynamic trails left by fish. These whiskers:
• Features unique undulating geometry that suppresses vortex-induced vibrations (VIV)
•Remain highly sensitive to wake-induced vibrations (WIV)
•Can detect disturbances at distances 2.5-10× their diameter
Current underwater sensors face significant limitations in turbid conditions where optical and acoustic methods fail. Biomimetic whisker sensors offer a revolutionary alternative for underwater navigation, particularly in challenging environments.



Preliminary Results

Undulating seal whisker geometry exhibits a 90% reduction in self-induced vibrations (VIV) compared to cylindrical sensors while maintaining a 5× higher sensitivity to wake-induced vibrations (WIV) in simulation tests.

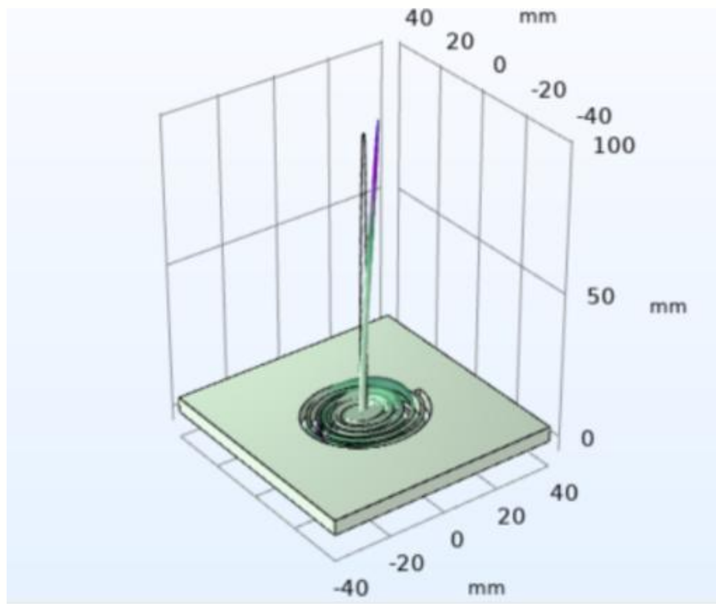


Fig 1: COMSOL Frequency Analysis of Seal Whisker Geometry

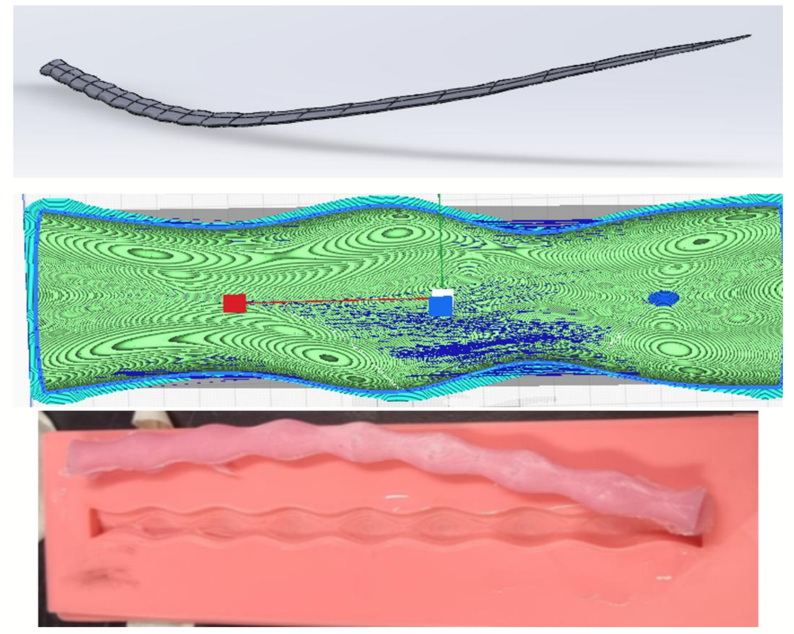


Fig 2: 3D CAD Model and Printed Whisker Prototype

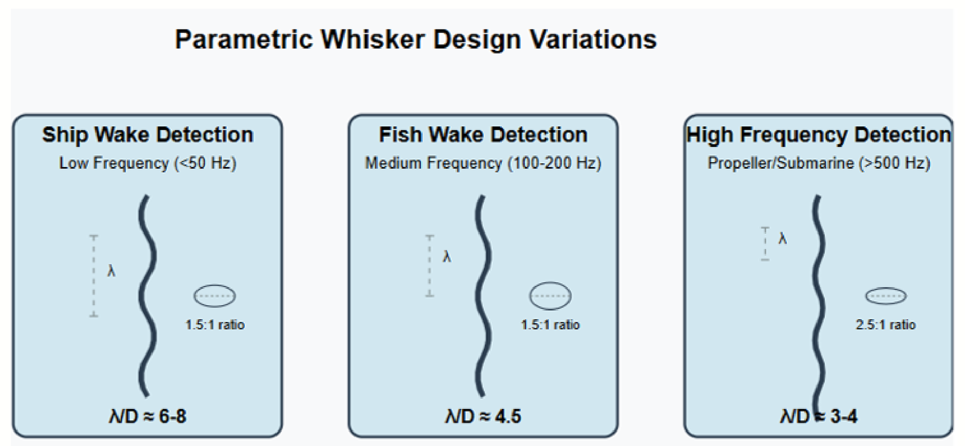


Fig 3: Parametric Whisker Designs for Application-Specific Detection

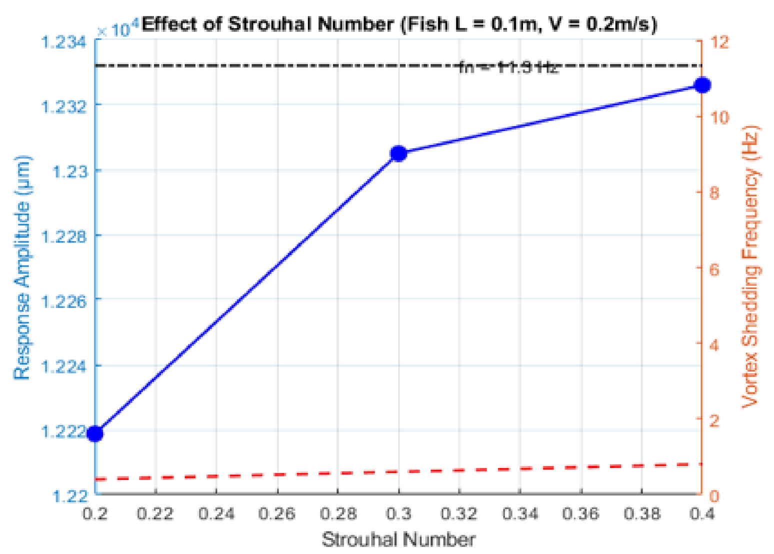


Fig 4: Strouhal Number vs. Response Amplitude and Vortex Shedding Frequency

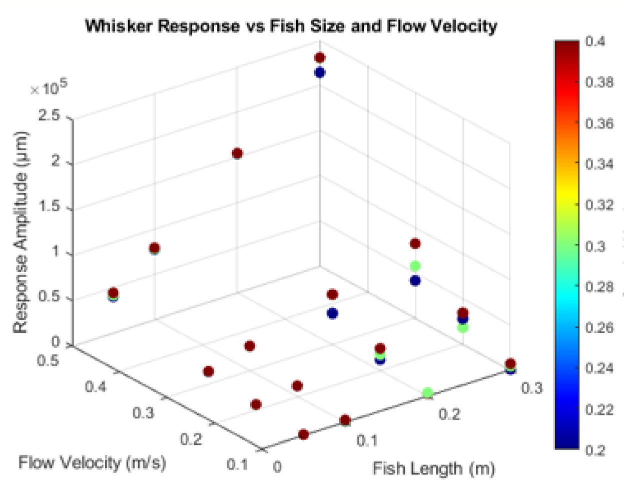


Fig 5: 3D Response Profile: Whisker Sensitivity to Fish Size and Flow Velocity

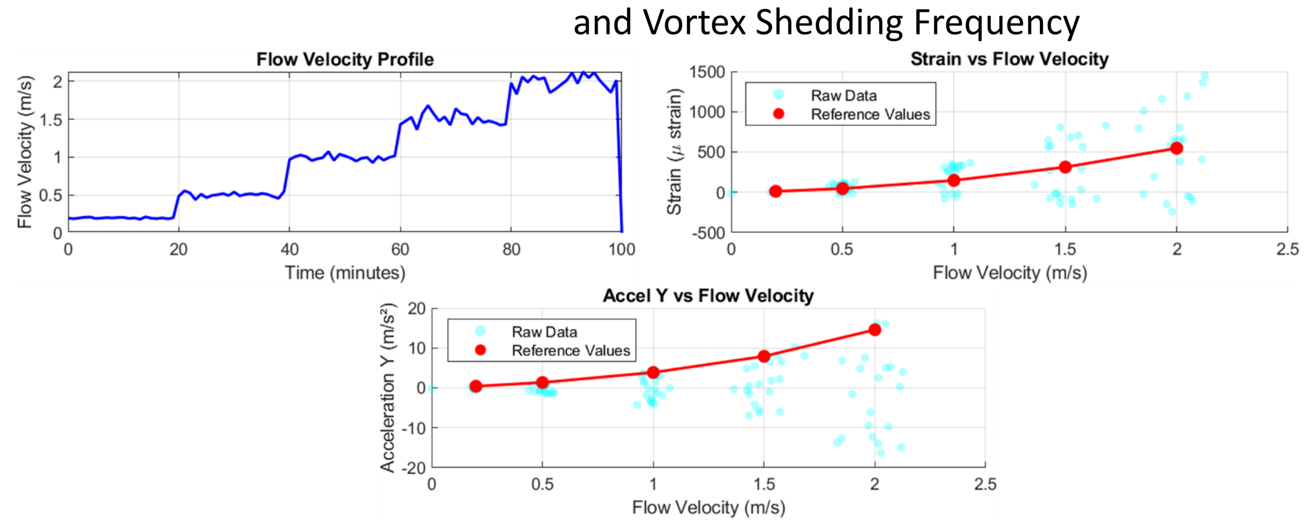


Fig 6: Comparative Sensor Data: Flow Velocity, Strain, and Acceleration Analysis

References

•Hanke, W., et al. (2010). "Harbor seal vibrissa morphology suppresses vortex-induced vibrations." Journal of Experimental Biology, 213(15), 2665-2672.
•Beem, H.R., et al. (2012). "Hydrodynamic sensing and behavior by seals and sea lions." Journal of Fluid Mechanics, 698, 235-256.

Methodology

Computational Modeling
•3D modeling of harbor seal whiskers with varied geometric ratios to optimize undulating morphology
•CFD simulations analyzing fluid flow around whisker geometries
•Fluid-structure interaction analysis to predict vibration response
•FFT and spectral analysis of vibration signals

Experimental Setup
•Water channel with controlled flow conditions (0.1-1.0 m/s)
•Instrumented whisker prototypes with strain gauges, accelerometers, laser sensors, and force sensors
•High-resolution imaging system for wake visualization
•Robotic fish models to simulate biologically relevant disturbances

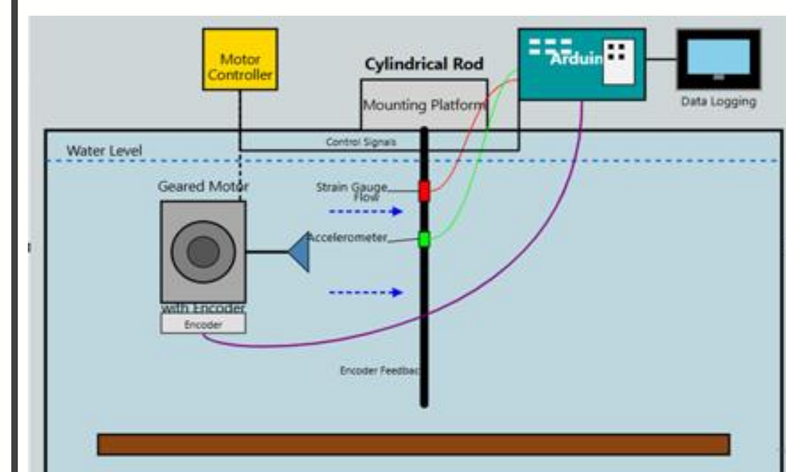


Fig 7a: Experimental Setup: Cylindrical Rod with Sensors

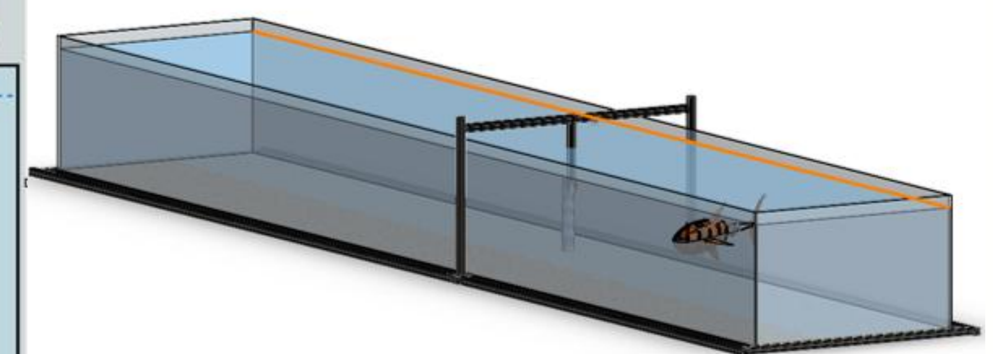


Fig 7b: Test Configuration: Seal Whisker Model with Robotic Fish

Future Work

•Develop application-specific whisker designs with optimized λ/D ratios:
- Ship detection (λ/D: 6-8, <50 Hz)
- Fish tracking (λ/D: 4.5, 100-200 Hz)
- High-frequency sensing (λ/D: 3-4, >500 Hz)

•Test with robotic fish to measure WIV/VIV ratios
•Evaluate structural integrity via Cauchy number analysis
•Benchmark against conventional sensors to quantify performance gains

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Ira A. Fulton Schools of Engineering
Arizona State University