WhiskerSense: Decoding Hydrodynamic Trails for Covert Underwater Tracking

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Objective and Research question

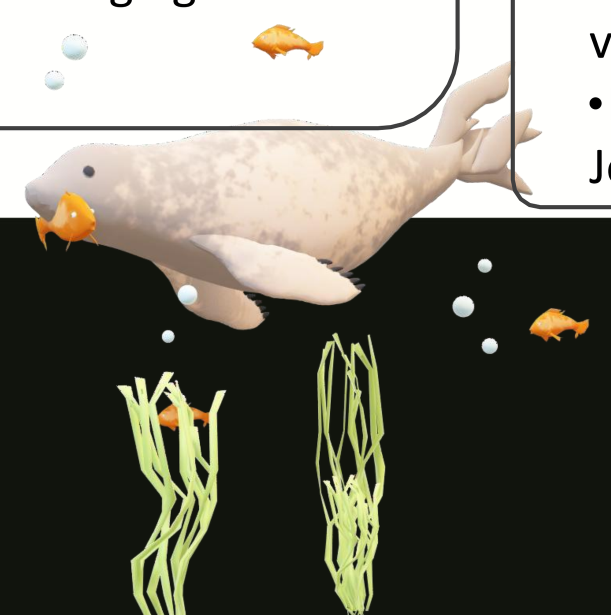
To develop and optimize nature–inspired sensors modeled after harbor seal whiskers that can revolutionize underwater robotics navigation. **Primary question:** How can the unique hydrodynamic properties of seal whiskers be engineered to maximize wake detection capabilities while minimizing self–induced 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, base structure) for amplification and 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) .

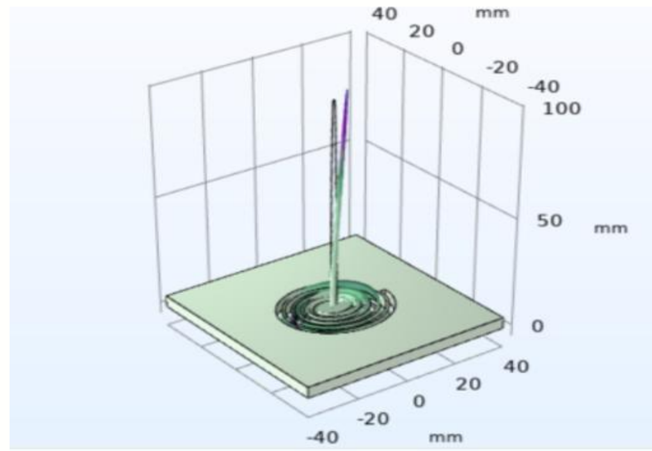


Fig 1: COMSOL Frequency Analysis of Seal Whisker Geometry

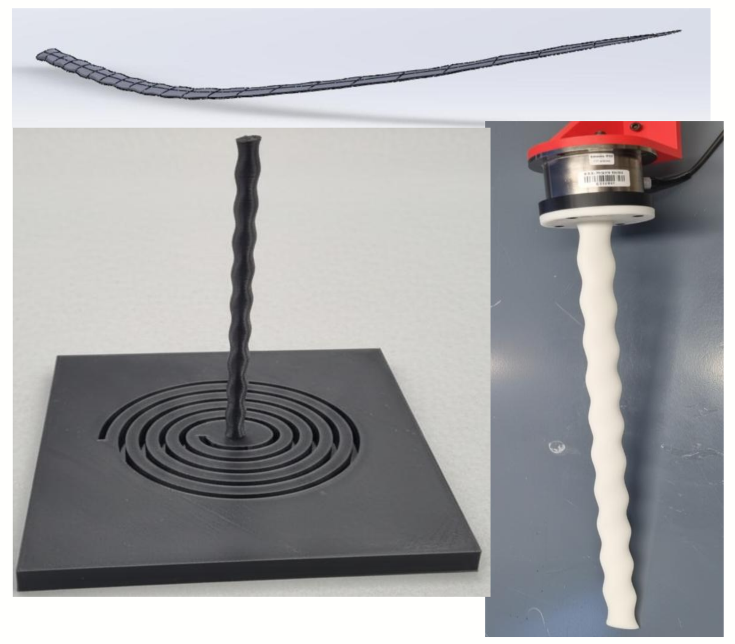


Fig 2: 3D CAD Model and Printed Whisker Prototype

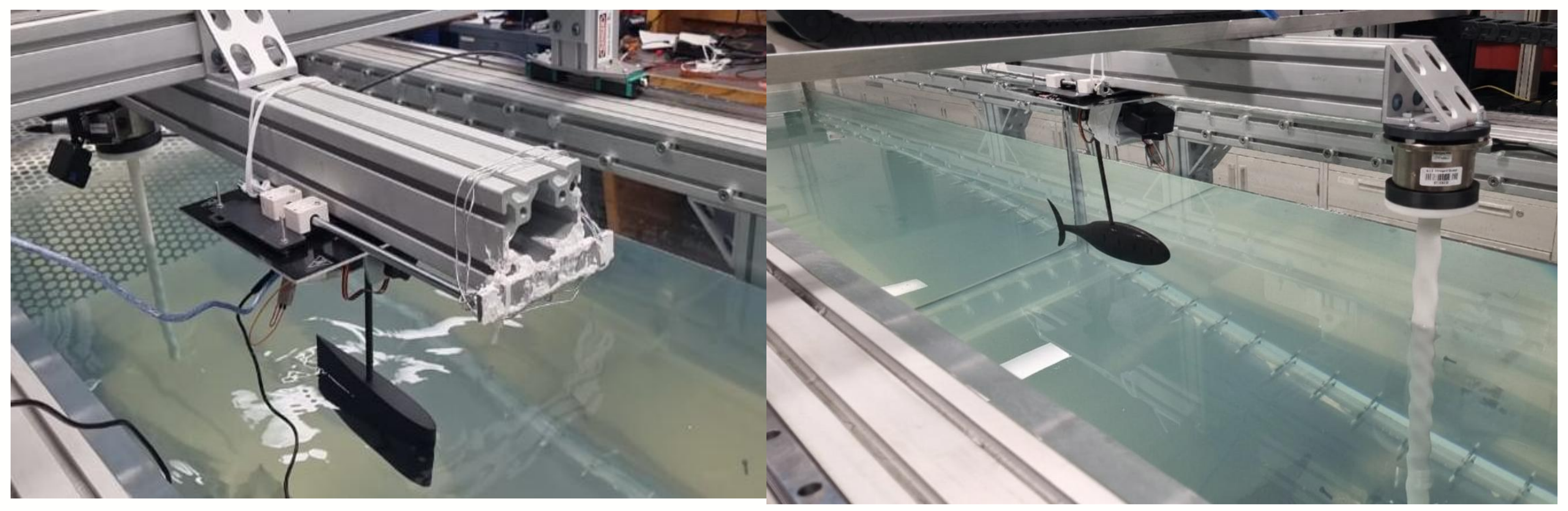


Fig 3: Experimental Setup to test Seal Whisker response with dynamic NACA 0012 Airfoil and robotic fish

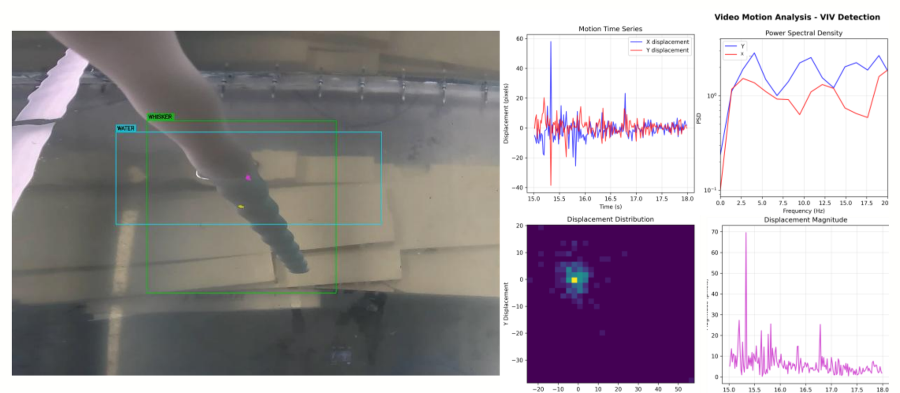


Fig 4: OpenCV analysis of Whisker showing VIV suppression

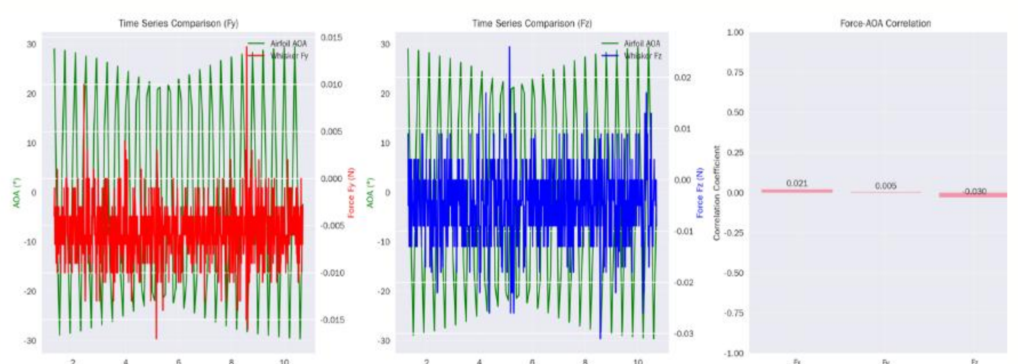


Fig 5: Frequency response of Airfoil flapping vs Seal Whisker

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 and bases to optimize undulating morphology
•Fluid–structure interaction analysis to predict vibration response
•FFT and spectral analysis of vibration signals
•OpenCV and frequency analysis with input response from airfoil and output response from whisker

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

Fig 7a: Bio-mimicked Robotic fish developed for this study

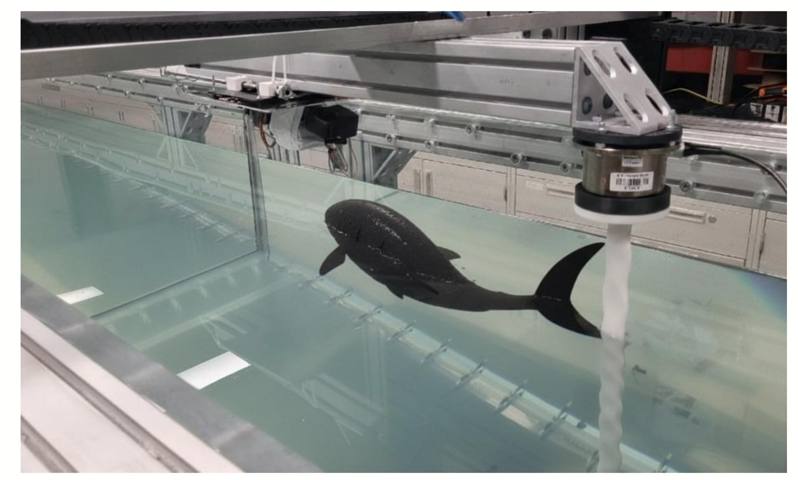


Fig 7b: Test Configuration: Seal Whisker with Robotic Fish developed for this study

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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