SENSING & SIGNALING

High-Sensitivity Pressure and Vibration Sensing

How biology detects sub-Pascal pressure changes with zero energy input

5	3	1–5	5
convergent strategies	principle clusters	TRL range	featured strategies

PROBLEM FRAMING

Pressure sensors for structural health monitoring, flow sensing, and tactile robotics require high sensitivity, low power, and broad bandwidth. Biological mechanosensors — lateral line systems, hair cells, spider slit sensors — achieve sensitivity at the thermal noise floor with passive architectures.

Application domains: robotics, aerospace, medicine

Principle cluster: mechanosensing, piezoelectricity, fluid dynamics

Physics & Mechanism

Underlying physics

[DRAFT] Biological mechanosensors convert mechanical deformation to electrical signals through ion channel gating (hair cells) or piezoreceptor activation. Hair cells in the cochlea detect displacement amplitudes below 1 ångström (0.1 nm) — approaching the Brownian motion noise floor (50 pm at room temperature in aqueous medium). The physics of detection limit: Brownian force noise $S_f = 4k_BT\cdot\gamma$ (γ = viscous drag coefficient), giving minimum detectable force in a 1 Hz bandwidth of ~4 fN for a cochlear hair bundle. Fish lateral line cupulas (100–500 μm diameter gelatinous domes over hair cell clusters) achieve 1–5 μm displacement sensitivity at 10 Hz. Engineering analogues: MEMS cantilever arrays with piezoresistive readout achieve 1 mPa sensitivity; piezoelectric PVDF polymer films detect 0.1 mPa in compressive mode. Spider slit sensilla (crack-like sensors in leg cuticle, 10–160 μm long) achieve strain sensitivity of ~10■■ — the highest of any known mechanosensor. [END DRAFT]

Biological Strategies

Move in/on Liquids Grey seal · TRL 3/9 · 59 genera

Nature tackled the monitoring of surrounding fluid motion problem in many different, yet fundamentally similar, forms. Many terrestrial and aquatic species have developed hair and whisker sensory systems each specially suited to its environment and designed to observe the fluid motion surrounding the animal. Such an ability to passively monitor wakes of objects is of vital importance to surveillan…

Design principle: It is essential to have well-documented data of seal whisker morphology with statistically meaningful generalization, as the solid foundation for whisker-inspired flow control applications. However, t

Differentiate Signal From Noise Grey seal · TRL 3/9 · 2 genera

Grey seals possess specialized whiskers with helical grooves and undulating cross-sections which disrupt water flow patterns around their heads, allowing them to detect minute pressure changes and distinguish prey signals from background noise. Such grooved structures create micro-vortices that dissipate large-scale turbulent eddies, effectively filtering out low-frequency noise while preserving h…

Design principle: Apply passive flow-shaping geometries to reduce noise generation in systems where aerodynamic or hydrodynamic vortices create unwanted acoustic signatures. Use helical or twisted surface profiles on c

Sense Touch and Mechanical Forces in a Living System Zebrafish (lateral line) · TRL 5/9 · 13 genera

As a flow-sensing organ, the lateral line system plays an important role in various behaviors of fish. An engineering equivalent of a biological lateral line is of great interest to the navigation and control of underwater robots and vehicles. A vibrating sphere, also known as a dipole source, can emulate the rhythmic movement of fins and body appendages, and has been widely used as a stimulus in …

Design principle: Treat hydrodynamic sensing as a distributed mechanosensory problem rather than a single pressure measurement. Emulate the zebrafish lateral line with arrays of compliant flow sensors positioned to cap

Sense Motion Zebrafish (lateral line) · TRL 1/9 · 1 genera

Potential flow theory is adopted to model the flow field around a fish's body in the presence of a Karman vortex street. Karman and reverse Karman streets represent the flow patterns behind a bluff body and a traveling fish, respectively. An analytical solution is obtained for a flat body, while a fish-like body is modeled using a Joukowski transformation and the corresponding equations are solved…

Design principle: Potential flow theory is adopted to model the flow field around a fish's body in the presence of a Karman vortex street. Karman and reverse Karman streets represent the flow patterns behind a bluff bo

Move in/on Liquids Zebrafish (lateral line) · TRL 3/9 · 59 genera

Using biological sensors, aquatic animals like fishes are capable of performing impressive behaviours such as super-manoeuvrability, hydrodynamic flow ‘vision’ and object localization with a success unmatched by human-engineered technologies. Inspired by the multiple functionalities of the ubiquitous lateral-line sensors of fishes, we developed flexible and surface-mountable arrays of micro-electr…

Design principle: To engineer such a biologically inspired sensing system, we developed an artificial lateral line using MEMS (microelectromechanical system) technology and explored its localization capability. Arrays

Combination Intelligence

Strategies that address different aspects of the same problem and are not redundant when combined.

Move in/on Liquids + Sense Touch and Mechanical Forces in a L

Shared principles: elasticity, fluid dynamics, mechanosensing, piezoelectricity

These strategies share 4 underlying principles including elasticity and fluid dynamics and mechanosensing. They may not be alternatives — combining them could address different scale regimes of the same problem simultaneously.

Sense Touch and Mechanical Forces in a L + Move in/on Liquids

Shared principles: fluid dynamics, gradient materials, mechanosensing, microfluidics

These strategies share 4 underlying principles including fluid dynamics and gradient materials and mechanosensing. They may not be alternatives — combining them could address different scale regimes of the same problem simultaneously.

Sense Touch and Mechanical Forces in a L + Sense Motion

Shared principles: fluid dynamics, gradient materials, mechanosensing

These strategies share 3 underlying principles including fluid dynamics and gradient materials and mechanosensing. They may not be alternatives — combining them could address different scale regimes of the same problem simultaneously.

EXPLORE THE INTERACTIVE VERSION

This report is a static synthesis. The interactive version includes live strategy cards, the Design Brief generator, Combination Intelligence engine, and filtering by TRL, scale, and principle.

`https://atlasofnature.org/challenge/pressure-vibration-sensing`

Atlas of Nature · atlasofnature.com · Generated 2026-03-21