

Pipebots: Bio-Inspired Micro-machines and the Future of Leak Detection and Prevention

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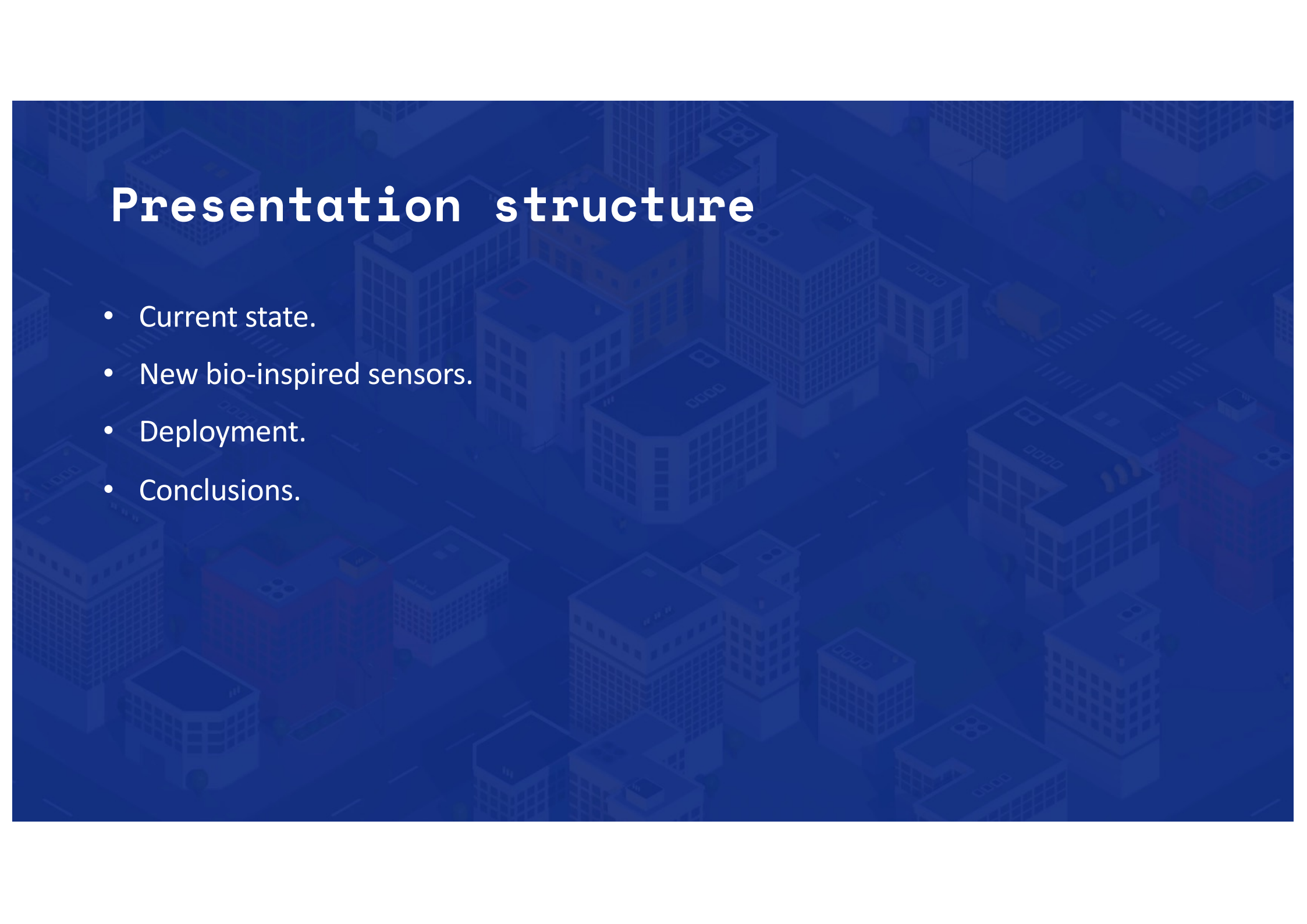
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The background of the slide is a dark blue isometric illustration of a city. It features numerous buildings of varying heights and shapes, some with grid-like patterns representing windows. Streets and roads are visible, with a few small, stylized vehicles. The overall aesthetic is modern and architectural.

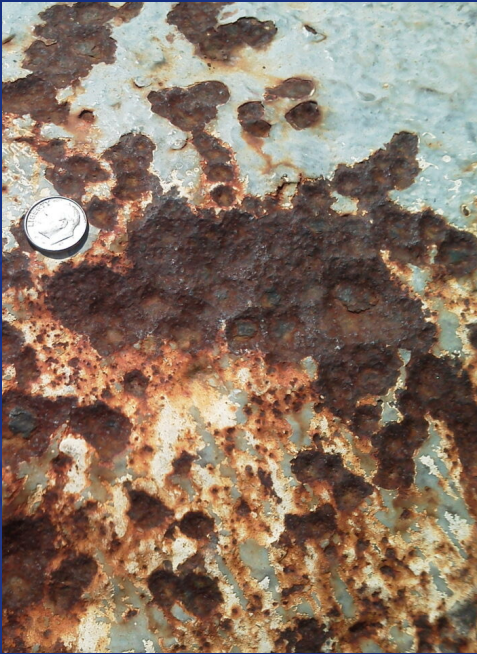
Presentation structure

- Current state.
- New bio-inspired sensors.
- Deployment.
- Conclusions.

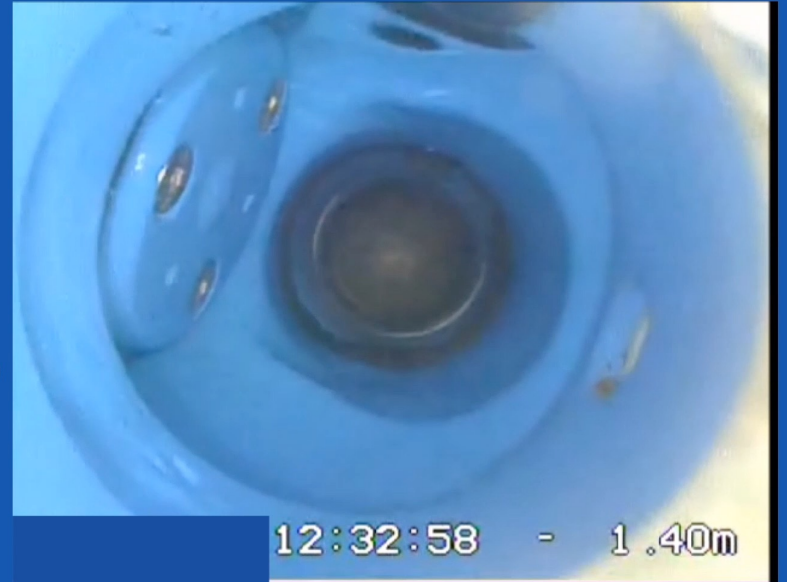
An isometric illustration of a cityscape with various buildings, streets, and a few vehicles, rendered in shades of blue and white. The text "The current state" is overlaid in the center.

The current state

The problem with pipes

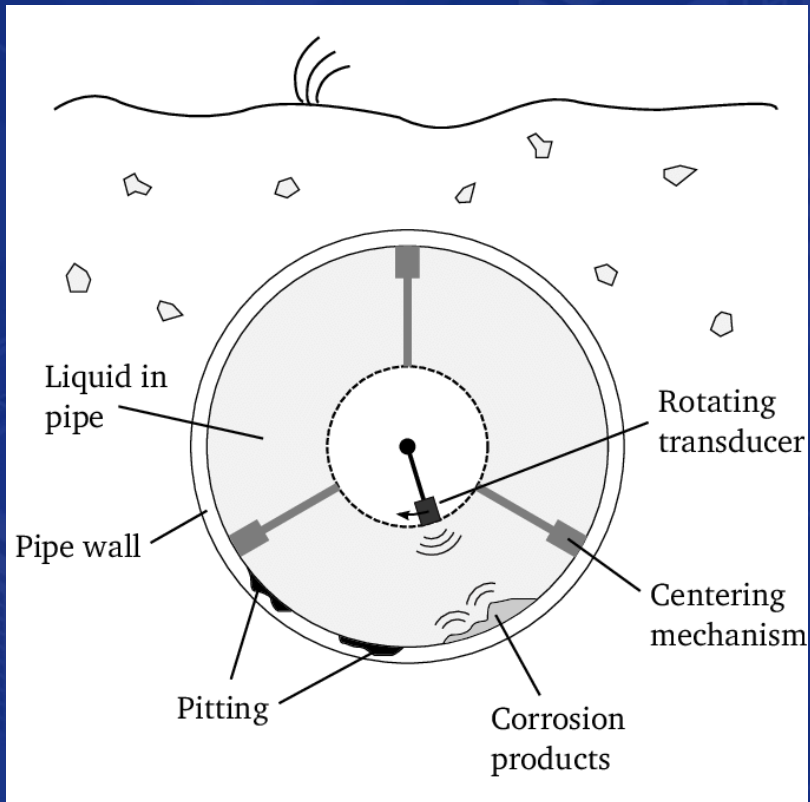


Live Water Pipe
Footage with
SynthoCam H2O



Courtesy of Synthotech

Most advanced NDT solutions

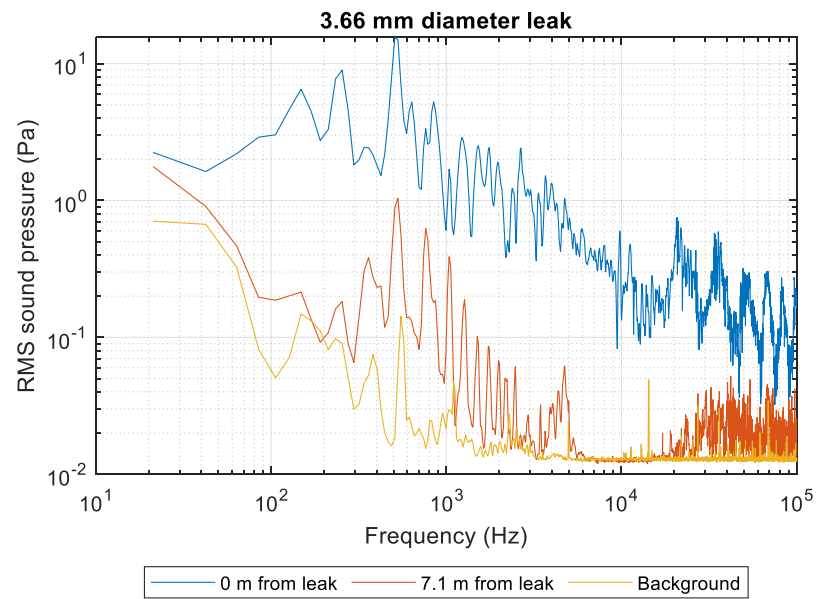


Widely adopted solution

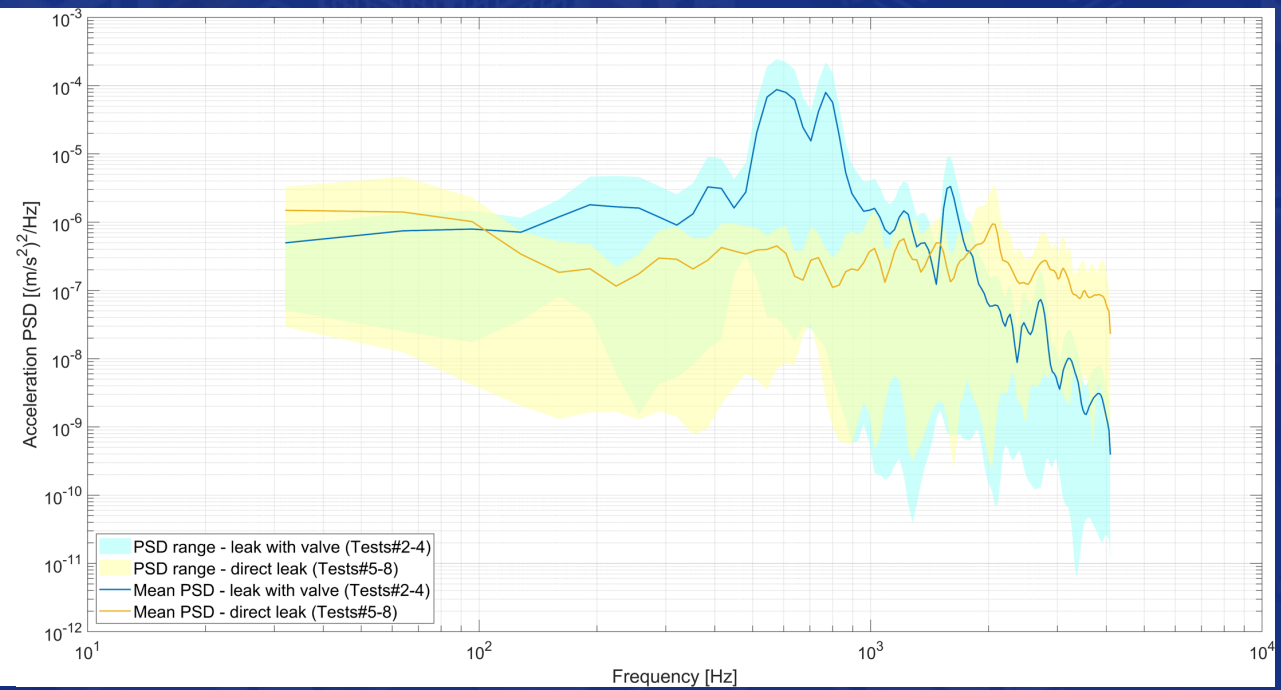


Challenges

Attenuation



Variability in leak signal spectrum



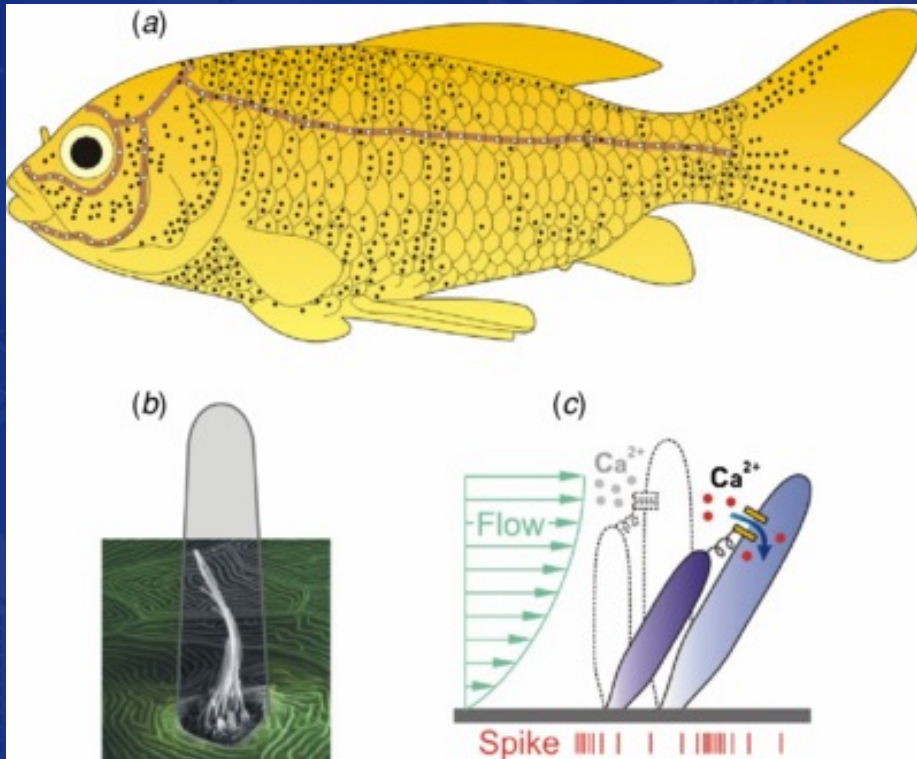
Summary

- The current technologies are too slow, disruptive and expensive to detect the location and severity of in-pipe defects that can lead to leakage.
- The current technologies for leak detection are affected by the poor visibility, acoustic attenuation and massive variability in the spectra of signals emitted by leaks.
- Proactive rehabilitation of buried pipes requires a step change in the accuracy in pipe condition detection and autonomous robotics to deliver new sensing solutions on a pervasive scale within the detectable range.
- There is also the need for a library of calibrated leak signatures to support the development of more robust future AI algorithms for leak detection and localisation.

An isometric illustration of a cityscape with various buildings, streets, and a few vehicles, rendered in a dark blue color scheme. The text "New bio-inspired sensors" is overlaid in the center in a white, sans-serif font.

New bio-inspired sensors

Why not to develop sensors inspired by the fish *lateral line*?

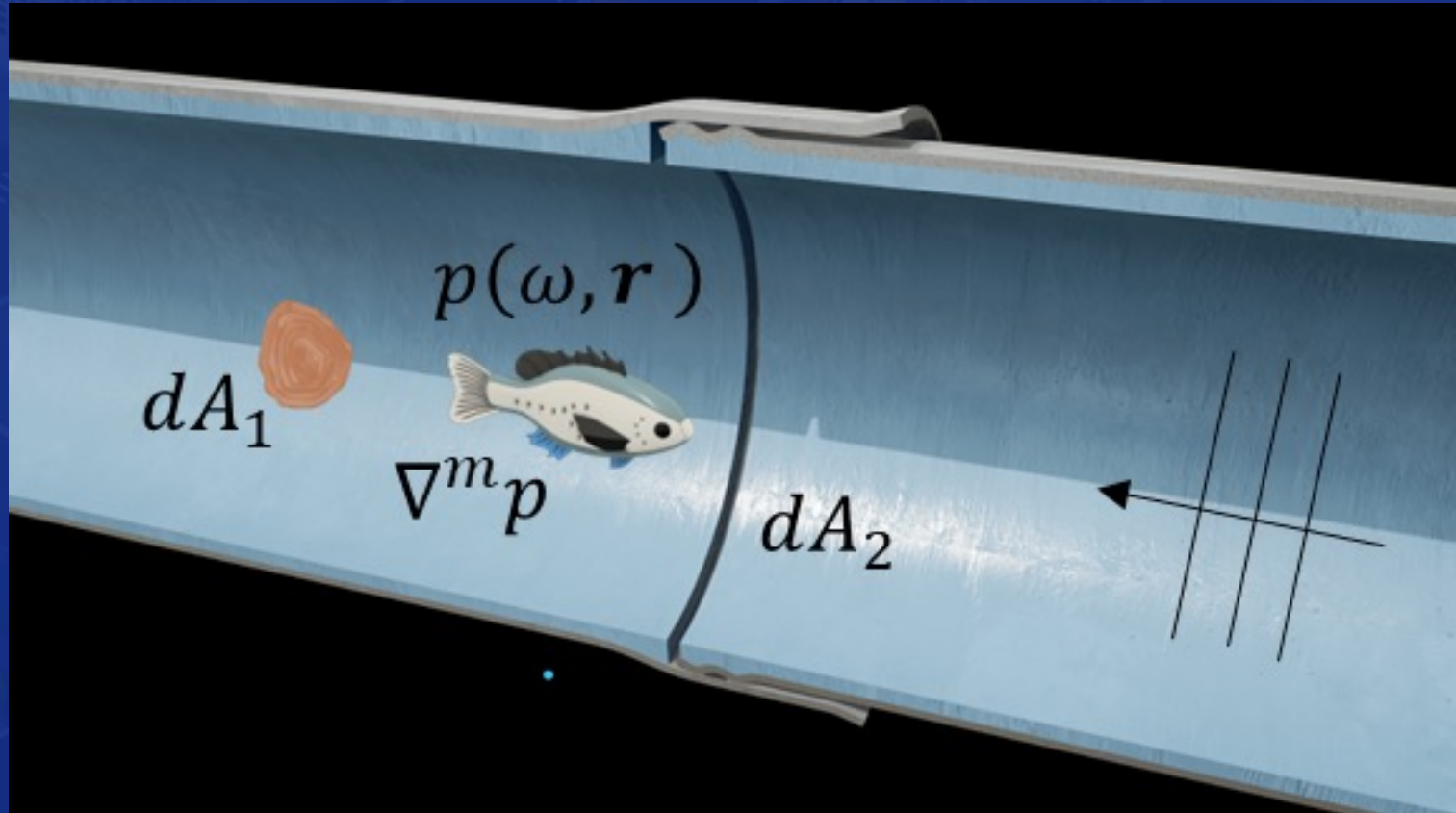


LATERAL LINE



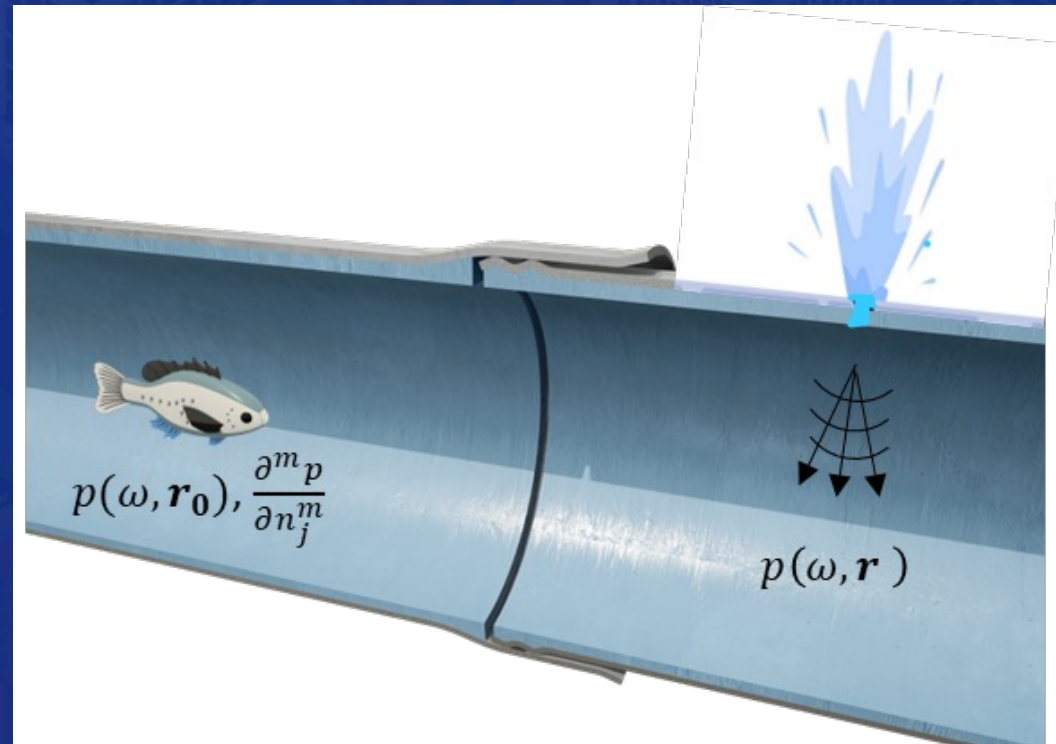
<https://youtu.be/c-v6ezb8jY4?si=UL2TIZYMk302CBTH>

Detecting a wall defect with lateral line



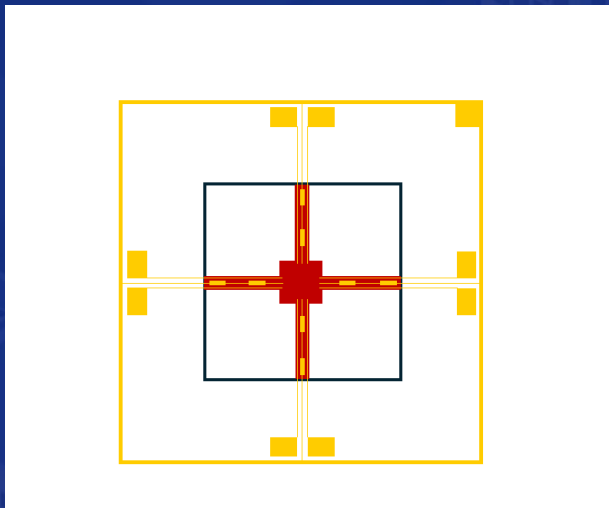
$$u_{1,2,3}(\omega, r) = \frac{\partial p(\omega, r)}{\rho \omega \partial n_j} = \frac{i}{\rho \omega} \iint \left[G(\omega, r|z') \frac{\partial^2}{\partial n_{1,2,3} \partial n_j} p(\omega, z') - p(\omega, z') \frac{\partial^2}{\partial n_{1,2,3} \partial n_j} G(\omega, r|z') \right]_{\Sigma A_k} dz'$$

Detecting water leak with lateral line

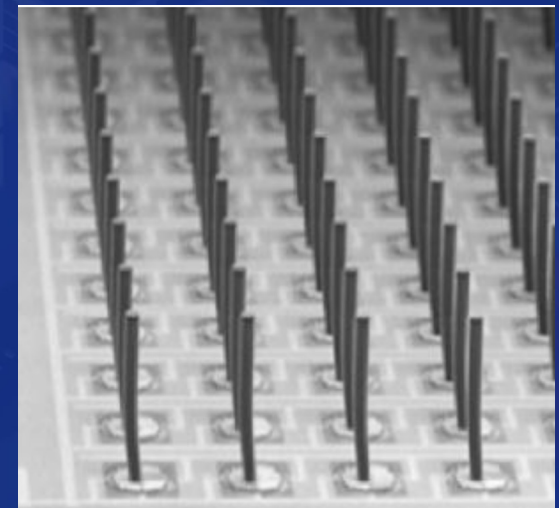
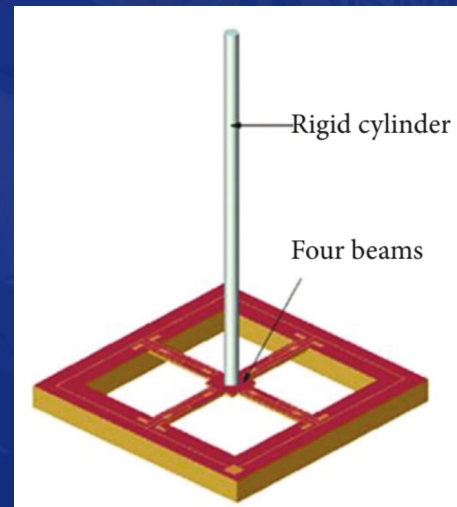


$$p(\mathbf{r}) = p(\mathbf{r}_0) + (\mathbf{r} - \mathbf{r}_0) \cdot \nabla p(\mathbf{r}_0) + \frac{1}{2} (\mathbf{r} - \mathbf{r}_0) \cdot \nabla^{(2)} p(\mathbf{r}_0) \cdot (\mathbf{r} - \mathbf{r}_0) + \dots$$

New micromachine sensors to mimic lateral line



5 mm



Quantities to be measured

$$\bar{\nabla} p = i\omega \bar{u}$$

sound pressure gradient (1 neuromast for 2 components)

$$\bar{\nabla} \bar{u}$$

acoustic velocity gradient (2+ neuromasts/component)

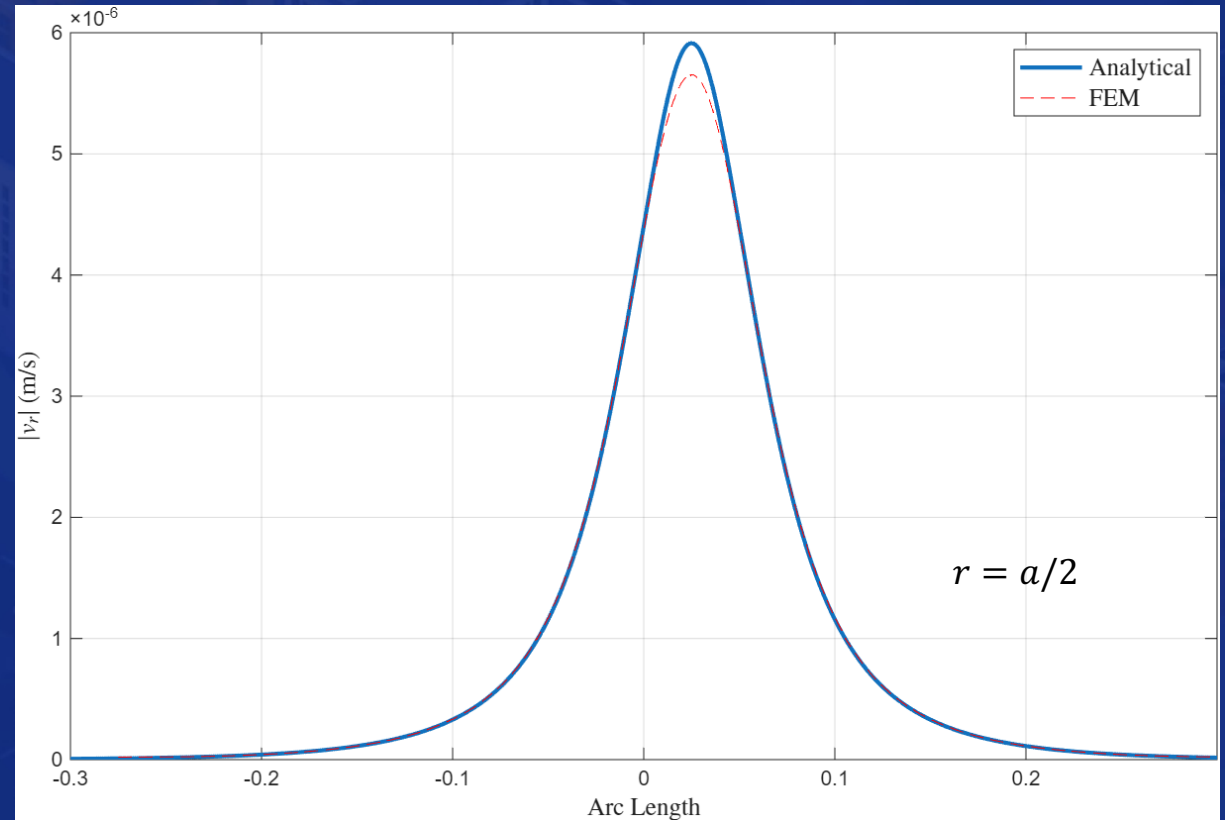
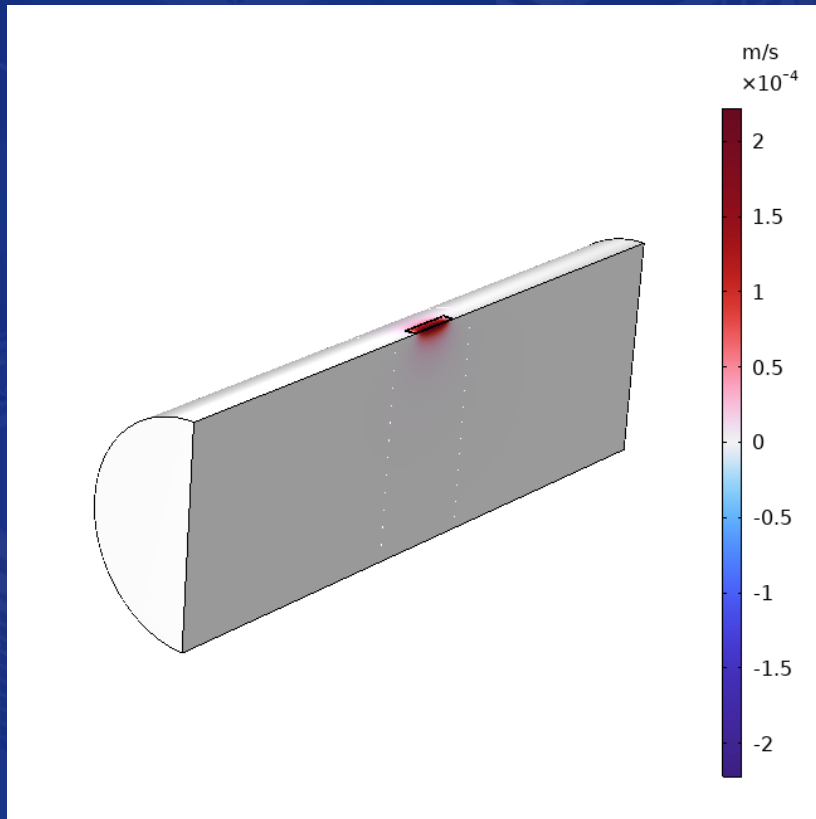
$$\bar{\nabla} \times \bar{u}$$

acoustic velocity curl (4+ neuromasts/component)

$$\nabla^{(k)} p$$

higher-order pressure derivatives, $k > 2$ (3D array of neuromasts)

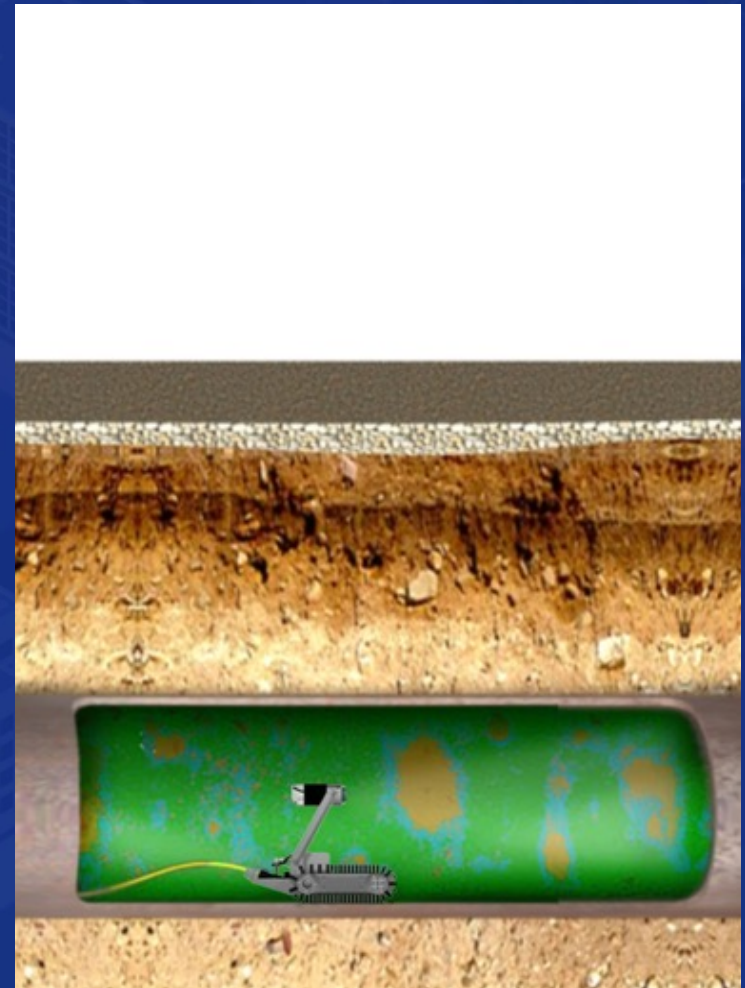
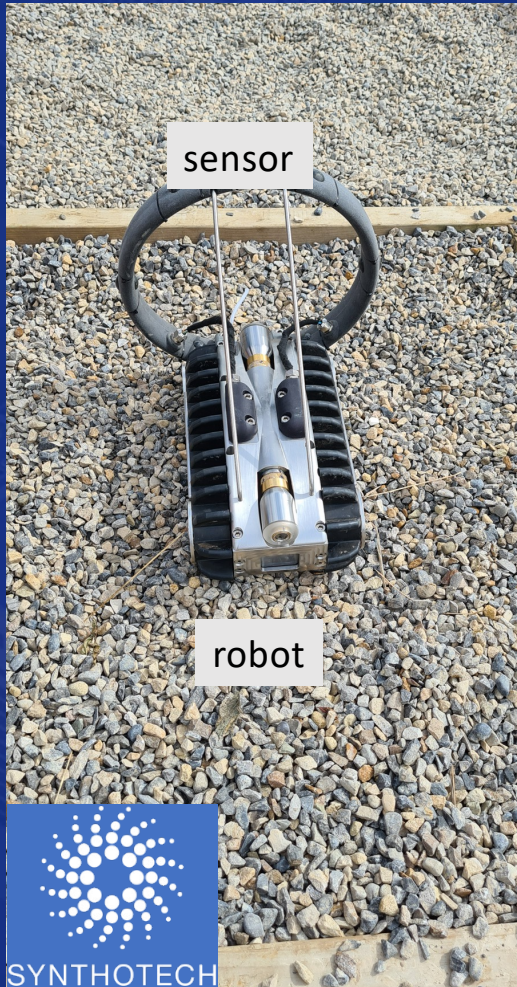
New theoretical foundation



An isometric illustration of a cityscape with various buildings, streets, and a few vehicles, rendered in a dark blue color scheme. The text "The deployment" is centered over the image.

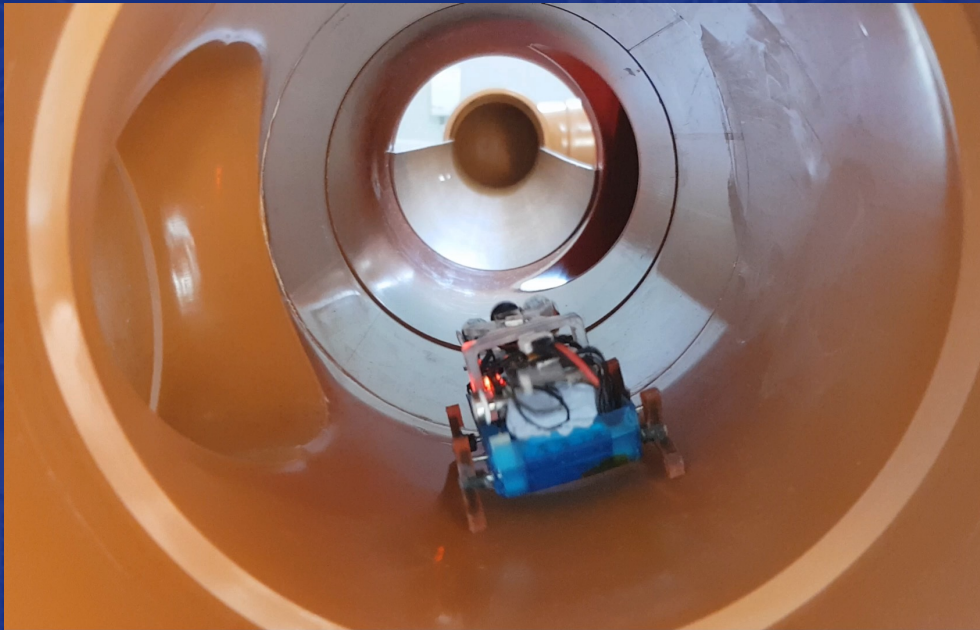
The deployment

Deployment for inspection

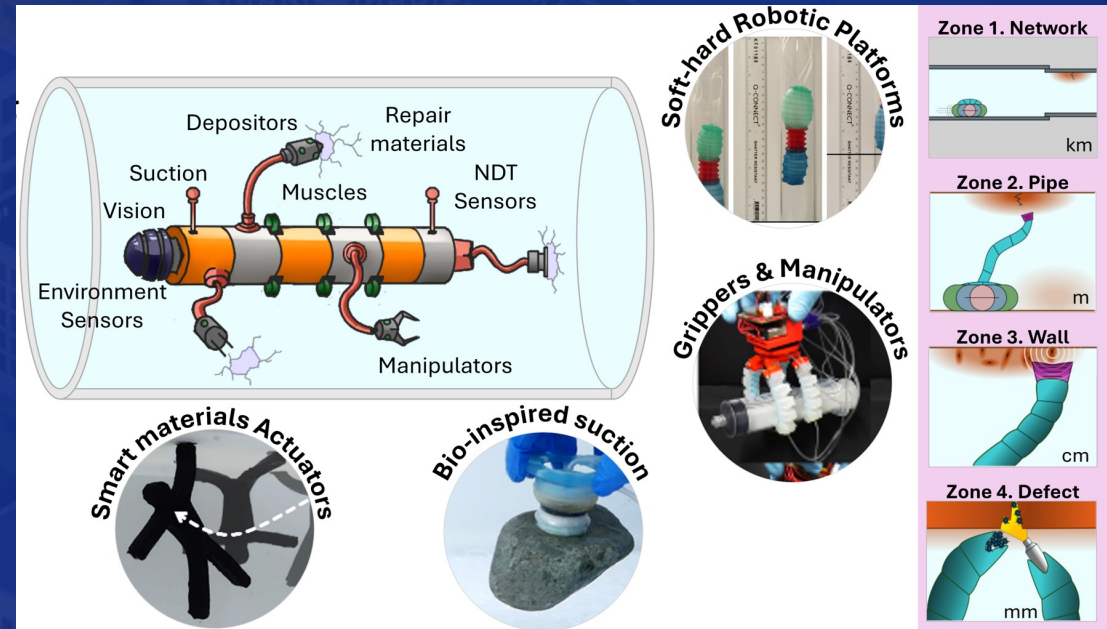


Deployment for repairs

Pipebots



Fixbots



Conclusions

- Bio-inspired sensors will provide a step change in the ability to detect the onset of critical defects leading to leaks and to detect leaks that are currently undetectable.
- The advent of autonomous robotics will enable to deploy these sensors on a massive scale to monitor and repair the pipes continuously and pervasively.
- It makes sense to carry out a campaign to measure a representative library of calibrated acoustic leak signatures to support the development of better AI algorithms.
- These technologies will contribute to the UK water sector commitment to half leakage by 2050 from the currently lost trillion litres/year.