Distributed Acoustic Sensing (DAS)

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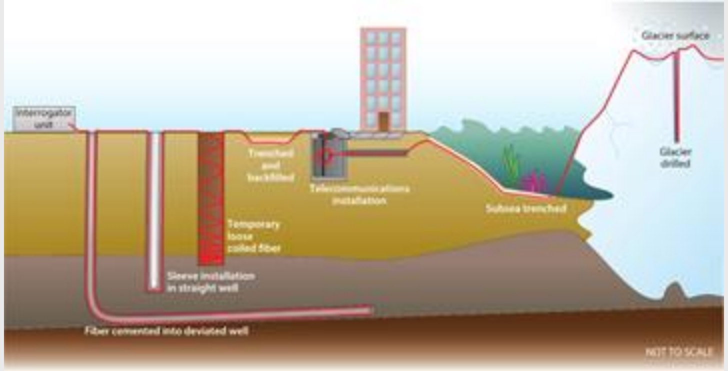
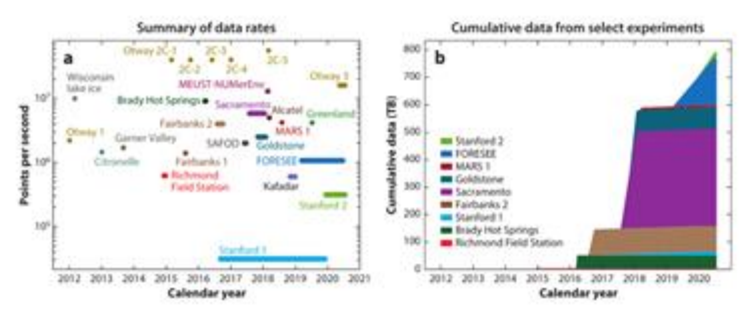
Introduction

- DAS is a geophysical sensing method that uses an optoelectronic instrument (interrogator unit) connected to optical fiber to measure strain along the fiber
- The interrogator unit sends laser pulses into the fiber and measures phase shifts in Rayleigh scattered light at each point in the fiber
- DAS can be used to study many processes or locations (urban areas, glaciers, earthquakes, etc)



Overview of Challenges

- As DAS develops into a continuous sensing method from a short term experimental method, the massive amount of data collection from high sample rate monitoring is a concern
    - 800 TB from 9 experiments
- Instrument availability, reproducibility of results, and standardization of data format are also listed as concerns that the authors believe need to be addressed before DAS becomes more widely used

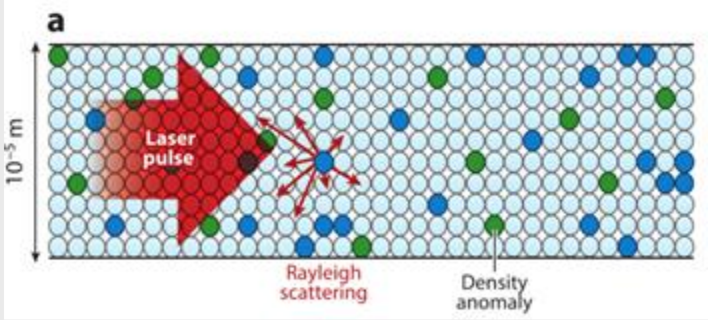


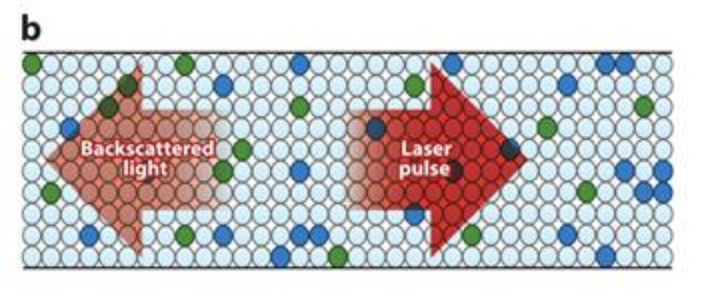
Distributed Acoustic Sensing Measurements

- DAS builds on prior work in optical strain sensing mainly by generating an array of dynamic strain measurements
- "DAS refers to any method in which optical interferometry is applied to laser light travelling inside an optical fiber to measure strain or stress rate at many positions along the fiber"

How DAS works

- The interrogator generates, sends, and receives a pulse of laser light in near infrared range (~1550nm)
  - Sometimes the interrogator uses continuous and swept-frequency light sources
- Refractive impurities cause some of the light to be backscattered (Rayleigh scattering)
- Rayleigh scattering is well studied in telecommunications as it causes drops in signal strength of ~0.15-0.20 dB/km





DAS Implementation

- The phase of the Rayleigh backscattered light can be analyzed with an optical time domain reflectometer
  - Assume simple straight there and back trajectory from the interrogator to the scattering point
  - Phase can be used to determine travel time (and where the scattering occurred)
  - Measurement is averaged over set increments of the fiber (gauge length)

Optoelectronic Interrogator

- In the interrogator, optical interferometry is applied to the backscattered signal to measure phase
- One approach is:
    - Pair of light pulses separated in frequency are launched sequentially
    - Backscattered light is measured at beat frequency ($|f_1 - f_2|$)
    - Backscattered signal phase is linearly related to gauge strain

pulse) separated by the gauge length (Masoudi & Newson 2016). The backscattered signal phase $\mathbf{\Delta\Phi}$ is linearly related to the gauge strain ϵ_{xx}, following

$$\epsilon_{xx}(t,x) = \frac{\lambda}{4\pi n_r x_g \psi} \mathbf{\Delta\Phi}, \qquad 1.$$

where t and x locate the axial strain measurement along the fiber axis ($+x$ direction), λ is the frequency used for measurement (beat frequency here), n_r and ψ are the refractive index and Pockels coefficient of the single mode fiber glass ($\psi = 0.79$), and x_g is the gauge length (Hartog 2017). This

Optoelectronic Interrogator

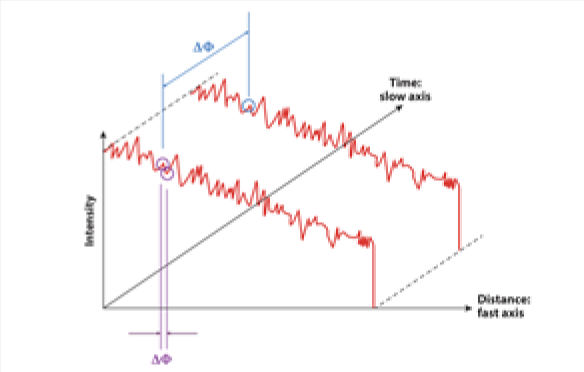
- Another approach is:
  - Inject one pulse
  - Analyze backscatter with Mehn-Zehnder interferometer and 3 x 3 coupler
  - Measure change in optical phase over time

Optoelectronic Interrogator

- Third approach:
    - Optical frequency domain reflectometry
    - Continuous frequency swept method
    - Backscattering combined with original light source creates range of beat signals whose frequency is linearly related to fiber position
    - Cross correlating OFDR signal traces over time reveals phase change information

Optoelectronic Interrogator

- Broadly, interrogator units measure phase between gauges at a single time (fast axis) or mixing signals at the same gauge over multiple pulses (slow axis)
  - This measures optical phase (strain) or optical phase rate (strain rate)

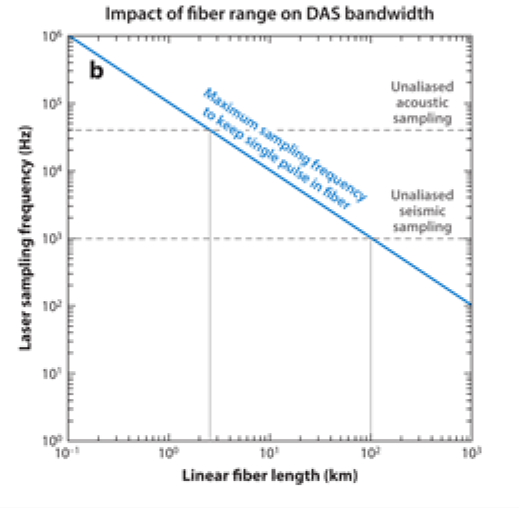


Other Notes

- Installation of fiber impacts quality of DAS data (cable materials, surrounding materials, coupling to surroundings, etc)
- Laser pulse firing rate is limited by light from one measurement reaching the end of the fiber and returning to the interrogator before the next measurement begins

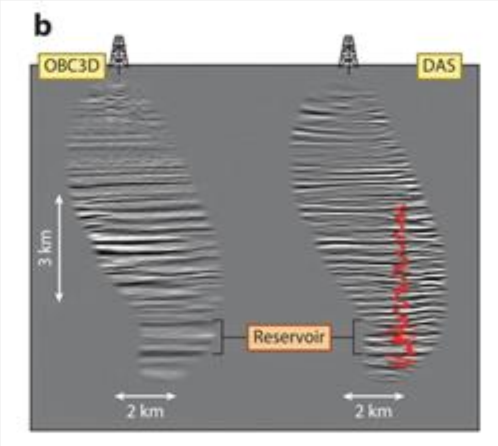
IU before the next measurement begins. The maximum pulse repetition rate f_R can be calculated from the refractive index n, and a known fiber length L, as

$$f_R = \frac{1}{L}\frac{c}{2 \cdot n}.$$



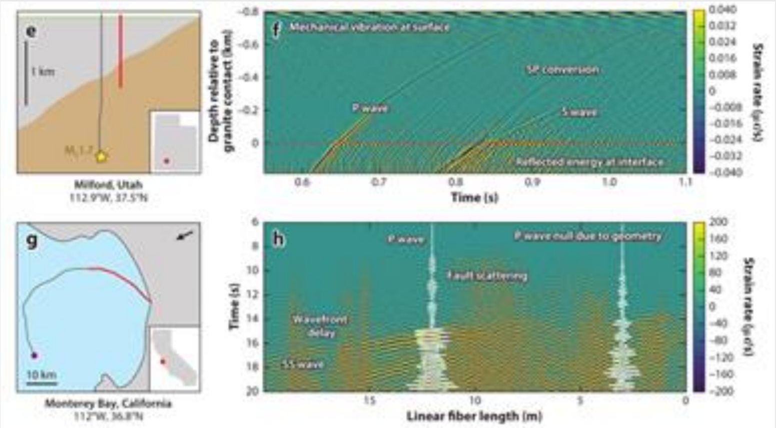
Applications to Subsurface Imaging

- DAS is suitable for large scale seismic sensing due to its aperture
- Shows better results in vertical seismic profiling for subsurface imaging than traditional methods
- With sufficient processing, DAS is also suitable for near surface ambient sensing (such as was shown in the Urban Sensing paper)



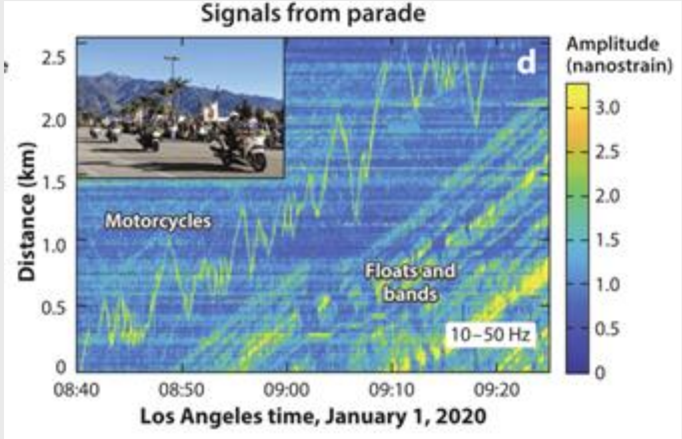
Earthquake Seismology

- Dense DAS channels serve as a good replacement for large seismic arrays (which require a lot of power and storage, are high maintenance, involve high labor, etc)
- Low power/cost sensors are an alternative but they are noisy and are not a good option for long term active sensing
- Can be used to monitor fracking, storms, quarry blasts, etc
- The main issues again, however, are generalizability



Infrastructure and Urban Monitoring

- The ability to plug in an interrogator to unused (dark) fiber in urban areas makes sensing a lot easier where the cost to deploy traditional seismic sensing systems would be too high
- ML + DAS signals can also be used for vehicle detection (cars, trucks, trains)
- Ambient noise from vehicles can be used for imaging or also to analyze human movement patterns without sensitive personal information (such as from tracking phones)
- Train infrastructure health monitoring is also made possible by DAS
- Structural monitoring is currently done with methods based on Brillouin and Raman scattering based techniques, but can be enhanced by DAS to sense higher frequency vibrations

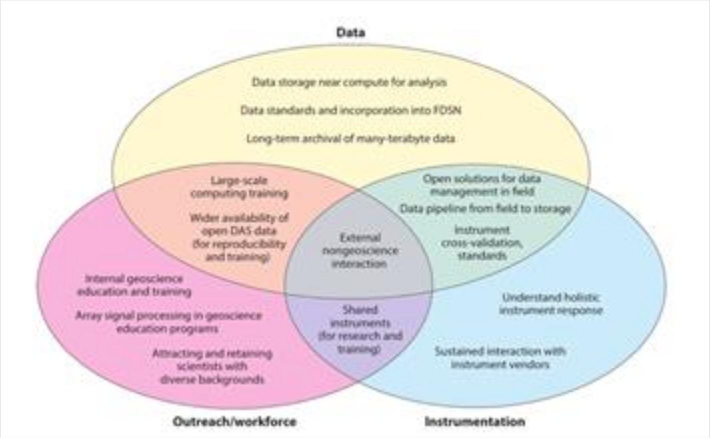


Cryosphere

- DAS can be used to monitor glaciers (some higher frequency events are harder to detect given coupling issues based on precipitation levels)
- Ocean sensing is somewhat more difficult because subsea fiber cables are designed to be robust, but it is still possible to detect teleseisms (tremors caused by far away earthquakes) and regional earthquakes

Current Issues + Future Needs

- DAS data is not shared across different research groups
- Public archives cannot support the large data volumes
- Most geophysicists do not have the training or computational skillset to acquire, manage, or analyze DAS data effectively
- Lack of standardized data format



Summary of Perusall

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