Distributed detection of temperature gradients with single-wavelength phase-sensitive OTDR and speckle analysis methods

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Motivation

- Traditional ΦOTDR allows for high-bandwidth vibration detection. → But provides no information on temperature changes along the fiber.
- Distributed temperature fiber sensing (ΦOTDR, Raman OTDR, BOTDA) require:

☆ More complex setups (→ and expensive) ☆ Longer measurement times (need frequency sweep and/or high averaging) → → → ☆ Incompatible with vibration detection

Goals

- Design of a cheap and *easy to implement* method which allows to extend the operation of traditional (single-frequency) ΦOTDR used for distributed vibration sensing, to the monitoring of distributed temperature gradients.
- Testing its reliability in a temperature-controlled oven *hot-spot*.

Measurement principle and experimental setup

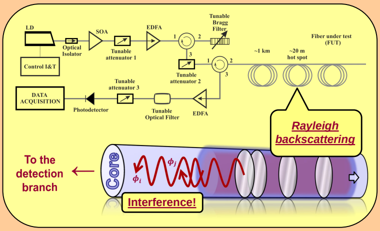
- 1 km fiber + 20 m *hot-spot* — $\lambda = 1550$ nm, $P_{length} = 20$ ns* *(spatial resolution ~2 m)
- Standard Φ-OTDR traces are measured @100 MS/s:

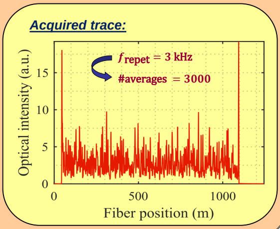
$$I(z) = |E(z)|^2 \Rightarrow \sum \sim \cos(\phi_i - \phi_j)$$

- The optical intensity variation $\Delta I(z) = I_k\text{-}I_{k-1}$ is:

$$\Delta I(z) \propto \sum_{i,j} r_i r_j \sin(\phi_i - \phi_j)\,\Delta n \qquad (\Delta n \propto -10^5 \Delta T)$$

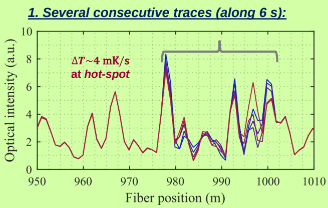
☆ ***Slow gradients make*** $\sin(\phi_i - \phi_j)$ ***linear!***

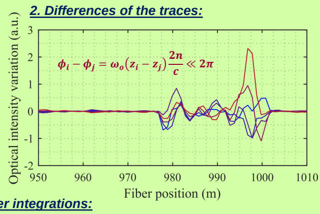




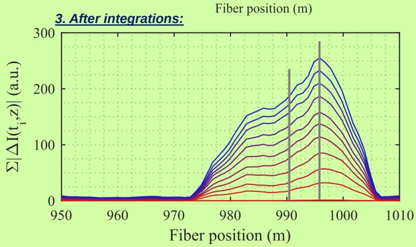
Experimental results

The temperature gradients detecting algorithm





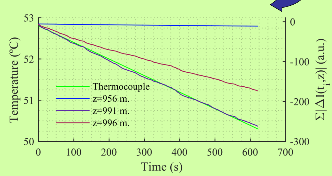
- Final processed signals:
  - Moving average (spatial integration)
  - Integration over time (accumulated ΔI)



Hot-spot measured temperature

Single points z are monitored along time.

The *hot-spot* was calibrated comparing with thermocouple.



The expected ***linear response is obtained*** for slow enough temperature gradients!

Acknowledgements

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Conclusions

- A simple and ***easy to implement*** **method** for temperature gradients detection in real time with **single-wavelength ΦOTDR** derived from the speckle analysis theory was presented and demonstrated.
- The method relies solely on a **low-cost post-processing** of the standard **ΦOTDR** traces (already acquired for vibration detection).
- Could be implemented **without affecting the distributed vibration detection** and with **a close to zero cost.**
- **A successful test** of it has been performed by measuring the temperature decrease of water into an oven as *hot-spot*.