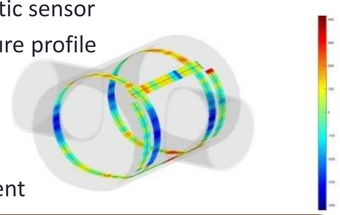
Brillouin scattering distributed fiber optic sensor- From static to dynamic

Linqing Luo
ll432@Berkeley.edu // ll432@cam.ac.uk

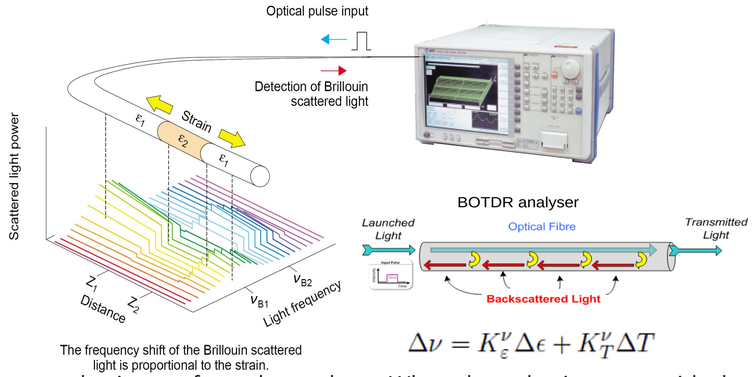
OBJECTIVE

To develop a robust distributed fiber optic sensor

- Accurate distributed strain/temperature profile
- Dynamic sensing
- Low cost system
- Long lifetime
- Whole life cycle sensing and assessment



BACKGROUND

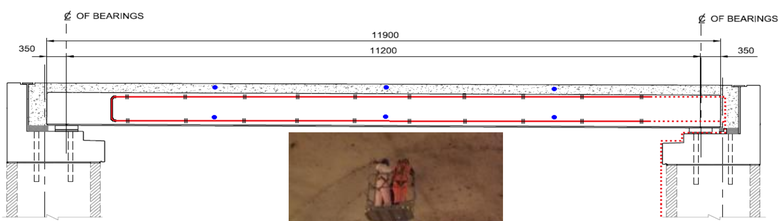


The frequency shift of the Brillouin scattered light is proportional to the strain.

$$\Delta\nu = K_\varepsilon^\nu \Delta\epsilon + K_T^\nu \Delta T$$

Laser pulse is sent from the analyzer. When the pulse interacts with the acoustic wave on the fiber at different location, a small volume of light will be scatted back with shifted frequency depending on different frequency and energy of the acoustic wave. By examining the shifted frequency, the strain/temperature along the fiber can be monitored.

However, current system is both expensive and has low resolution, especially in the dynamic measurement. Therefore, we need to design a suitable analyzer for civil engineering application.



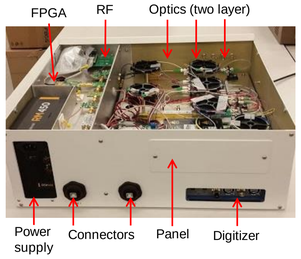
STATIC SENSING - PROTOTYPE A

Performance

- Length: 8 km
- Readout: every 20mm
- Data amount: up to 50,000 data pts/km
- Resolution: 20 με / 1 ℃

Feature

- Digital based - **Low cost**
- Advanced signal processing – **High performance**
- Dynamic sensing – **Better engineering assessment**



Prototype A

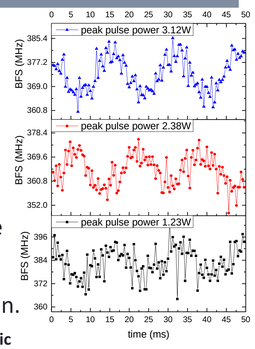
DYNAMIC SENSING - PROTOTYPE A

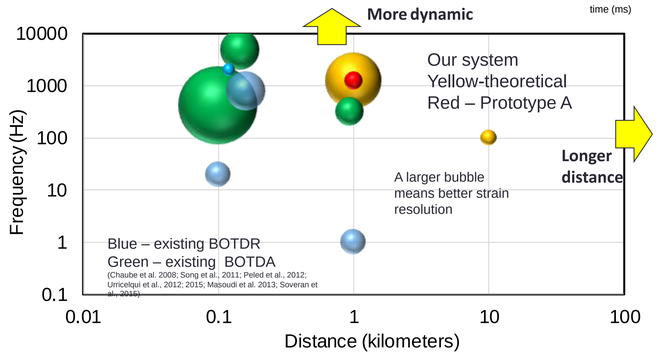
Experiment

- Shaker vibration at 60Hz with 2mm movement
- 6m fiber vibrated at the end of 1 km fiber
- 2.5kHz sampling rate

Result

- Different power gives different vibration profile
- In 3.12W, the resolution is about 80 με
- 60 Hz is clearly showed in the frequency domain.



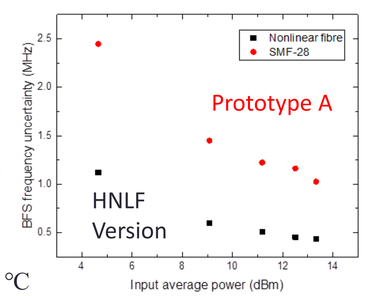


PERFORMANCE IMPROVEMENT 1

✓ ***Speed & Strain/temperature resolution***

Using highly nonlinear fiber (HNLF)

- Because the signal to noise ratio is improved, the measurement speed and be **5 times faster**
- The uncertainty is **half ->** 8 με / 0.4 ℃



PERFORMANCE IMPROVEMENT 2

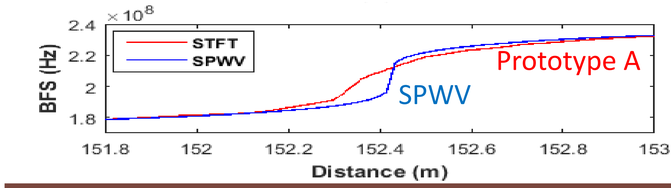
✓ ***Spatial & Strain/temperature resolution***

$$STFT_x(t,f) = \int_{-\infty}^{\infty} x(\tau)\omega(t-\tau)e^{-j2\pi f\tau}d\tau$$

$$SPWV_x(t,f) = \int_{-\infty}^{\infty} q(t-u)\int_{-\infty}^{\infty} \omega(\tau/2)\omega^*(-\tau/2)\, x(u+\tau/2)x^*(u-\tau/2)e^{-j2\pi f}d\tau du$$

Signal processing - SPWV

- Spatial resolution **improves with factor of 1.5**
- Strain/temperature **resolution improves with factor of 2.1**

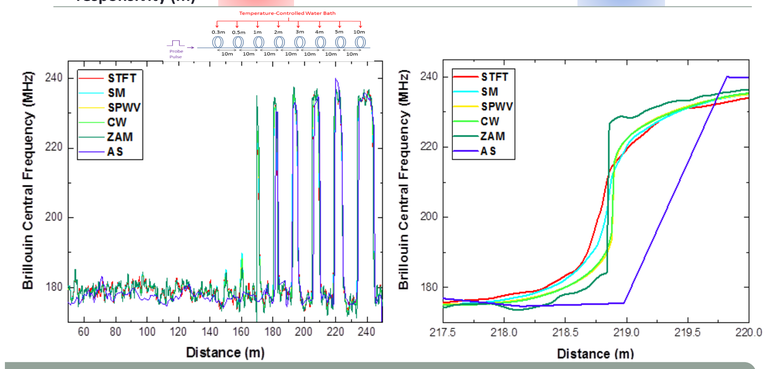


PERFORMANCE IMPROVEMENT 3

Spatial/Strain/temperature resolution

Signal processing – Quadratic time-frequency analyzing

T-F Transform	STFT	SM	SPWV	CW	ZAM	AS
Standard Deviation (℃)	1.67	1.48	1.12	1.45	1.72	1.58
Transition responsivity (m)	0.40	0.52	0.32	0.37	0.03	0.8



CONCLUSIONS

- A small gain STFT-BOTDR has been developed.

Performance in prototype A:

Length 8 km, Readout 20mm, resolution 20 με / 1 ℃, gauge length 1m, up to 1.5 kHz theoretically and 10-60 Hz has been proved.

Further developed versions:

- HNLF: Length 1km, readout 20mm, resolution 8 με / 0.4 ℃
- SPWV: Length 8km, readout 20mm, resolution 10 με / 0.5 ℃
- ZAM: Length 9km, readout 20mm, resolution 34 με / 1.72 ℃, spatial resolution 0.03m

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