# FBG-based Shape Sensor for Tracking a Fully Flexible Endoscope

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## Introduction:

- One of the main challenges in the MIRACLE project is to track the fully flexible endoscope once it enters the patient's body.
- Because of line-of-sight limitations and electromagnetic interference, the common tracking technologies can't be used.
- **FBG-based** sensors can provide 3D shape information with less than 1mm accuracy.

### 1. Fiber Bragg Grating:

- Bragg Gratings are periodical patterns in the core refractive index.
- They have high reflectivity in certain wavelengths called Bragg wave-length, which depends on the period length and the effective refractive index in the core area.

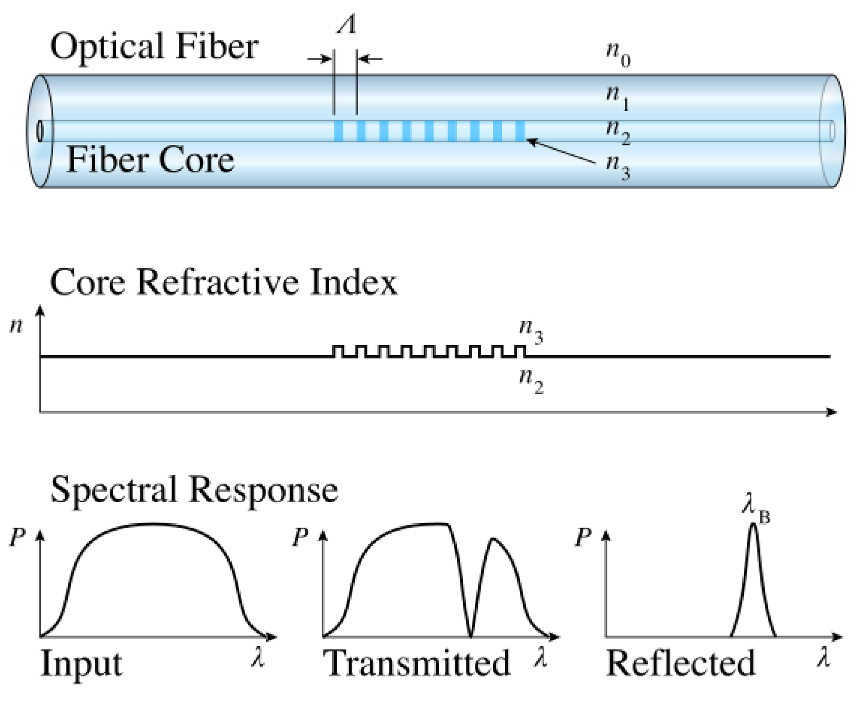


Fig 1: A Fiber Bragg Grating structure with refractive index profile and spectral response [1].

- Strain-optic, thermal expansion and thermo-optic effects make these structures sensitive to environmental perturbation (strain and temperature).

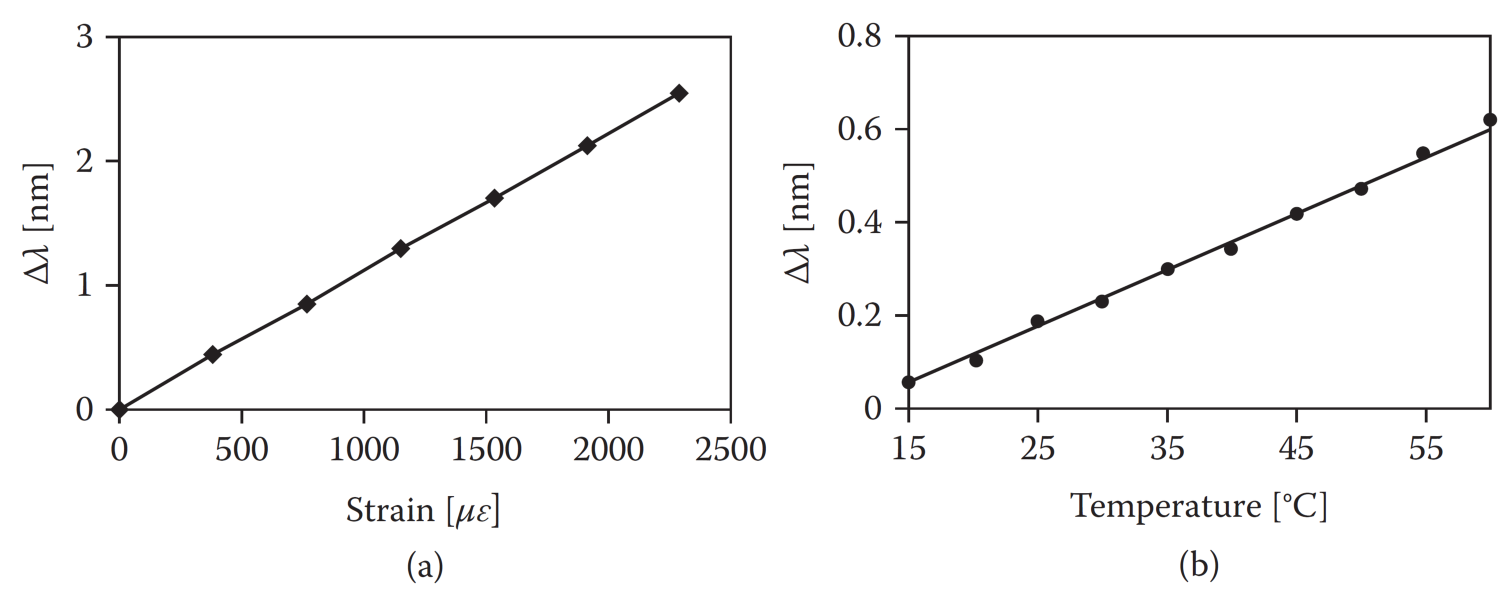


Fig 2: Typical wavelength-shifting response of an FBG to (a) strain and (b) temperature [2].

### 2. Shape Sensing:

Having at least two FBG sensor at each z-position, makes it possible to detect compression and expansion caused by bending.

**Sensor assembly methods:**

- Single mode fibers (SMF)
- Multi-core fibers
- Bragg grating waveguides in cladding area

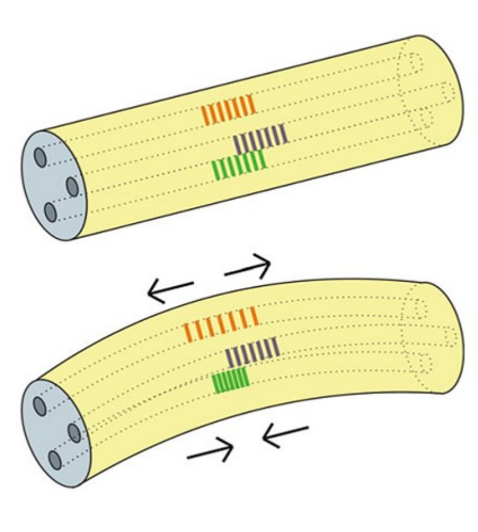

Fig 3: Expansion and compression while bending [2].

## Experimental Setup:

**Fibers:**

- Two arrays of 5 FBGs in SMFs
- Wavelength range:1515 -1585 nm
- FBGs 5cm apart

**Substrate:**

- Wire braided Polyimide
- 30 cm long
- 1.5 mm OD and 0.75 mm ID

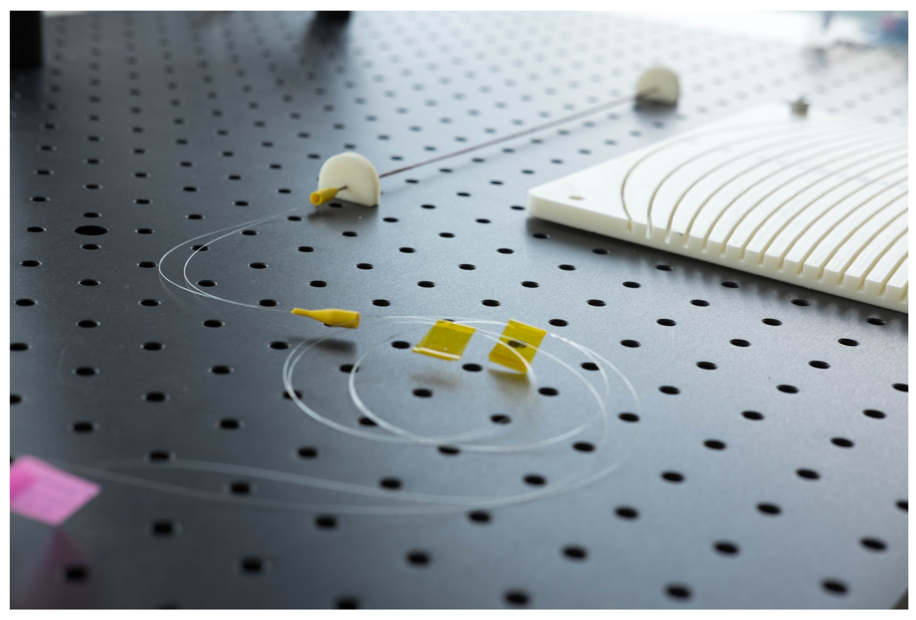

Fig 4: Sensor and calibration template.

**Calibration**:

- Curvature template (radius from 1 m to 0.2 m )
- Special fiber holders for orientation control

## Preliminary Results:

- There is a linear relationship between bending radius and Bragg wave-length shift.
- The sensor is sensitive to the bending direction.

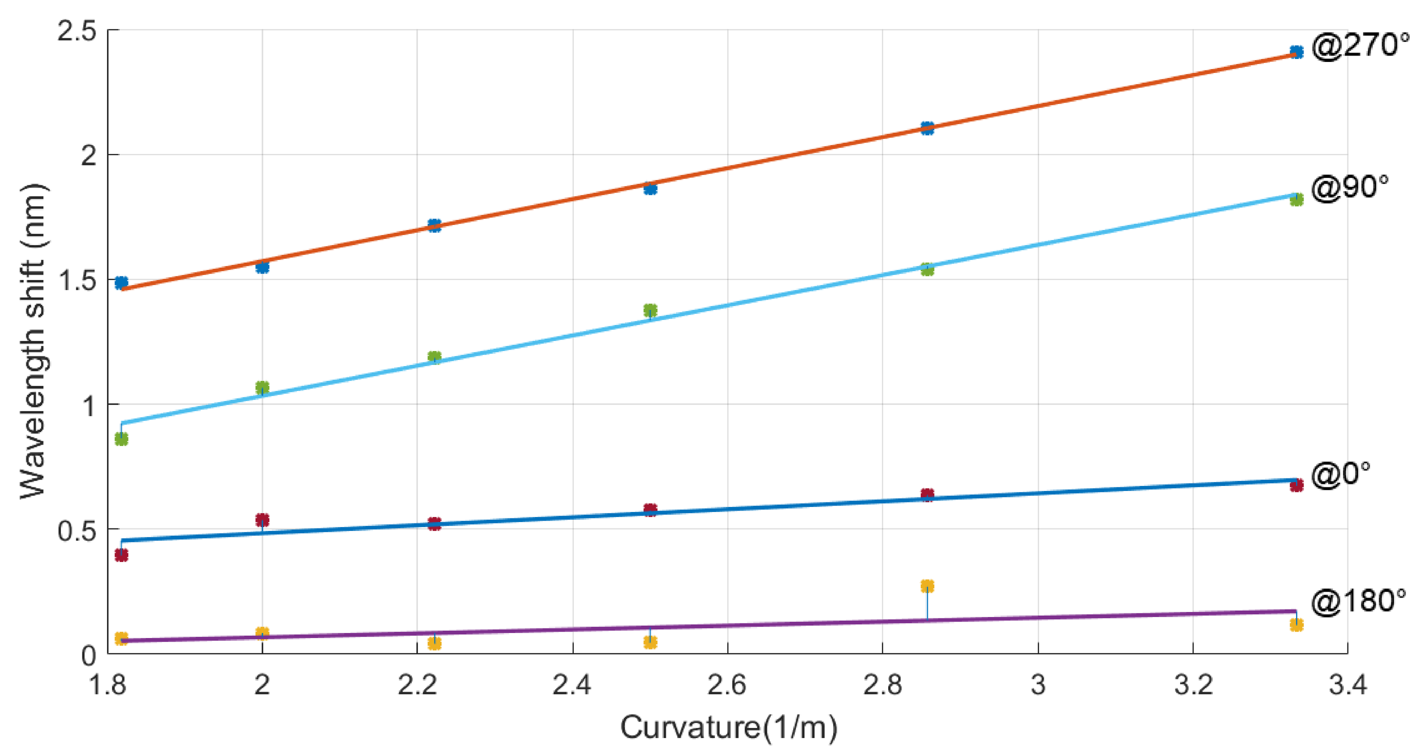


Fig 5: Bragg wavelength shift vs. curvature for different bending direction.

- Max positioning error @270° is around 0.1mm after each joint.

**Shape Reconstruction:**

Using the measured wavelength shift from 10 FBGs and some geometrical information, the radius of curvature and its direction can be calculated.

The 3D shape is reconstructed using the moving coordinate system.

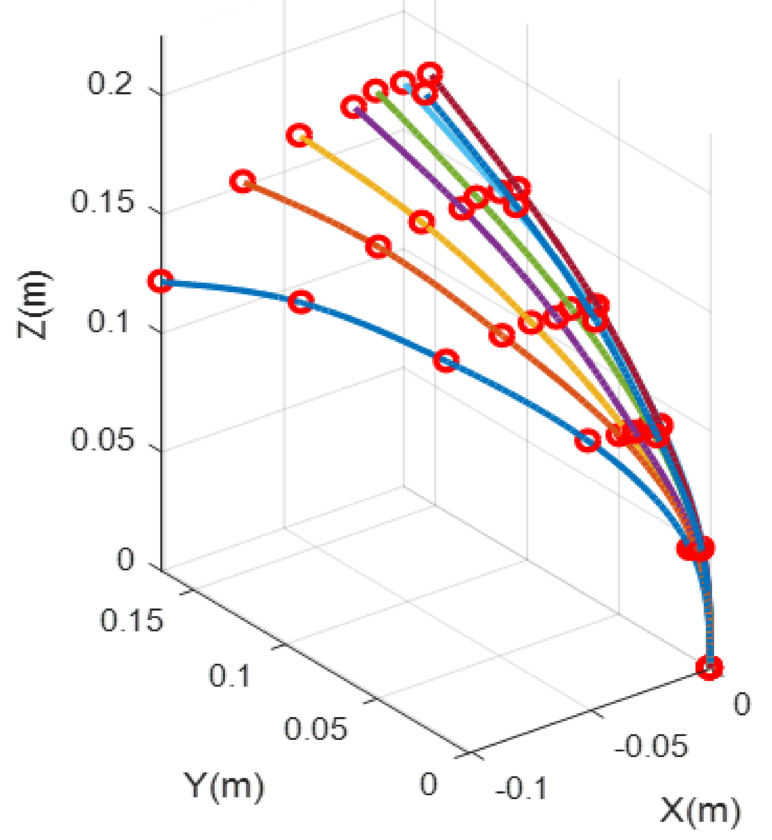


Fig 6: 3D reconstructed shape in different bending radii.

## References:

[1] Wikipedia.org

[2] G. Marowsky (ed.), *Planar Waveguides and other Confined Geometries: Theory, Technology, Production, and Novel Applications*, chapter 10, Springer Series in Optical Sciences 189 © Springer Science + Business Media New York 2015