FBG-based Shape Sensor for Tracking a Fully Flexible Endoscope

Universität Basel
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Project MIRACLE
Planning and Navigation
CIAN

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Motivation

Tracking the fully flexible endoscope inside the patient's body, is one of the main challenges in the MIRACLE project.
Among common tracking technologies, Fiber Bragg Grating (FBG)-based 3D-shape sensing is a promising approach, as FBGs are resistant to electro-magnetic interference and have no line-of-sight limitations.

Background

Fiber Bragg Grating:
It's a periodic variation of the core refractive index. An FBG shows large reflectivity around a certain wavelength which fulfills the Bragg condition. External perturbation (temperature/mechanical strain) can change the grating period, which causes a shift in the reflected signal (shown in Fig. 1).

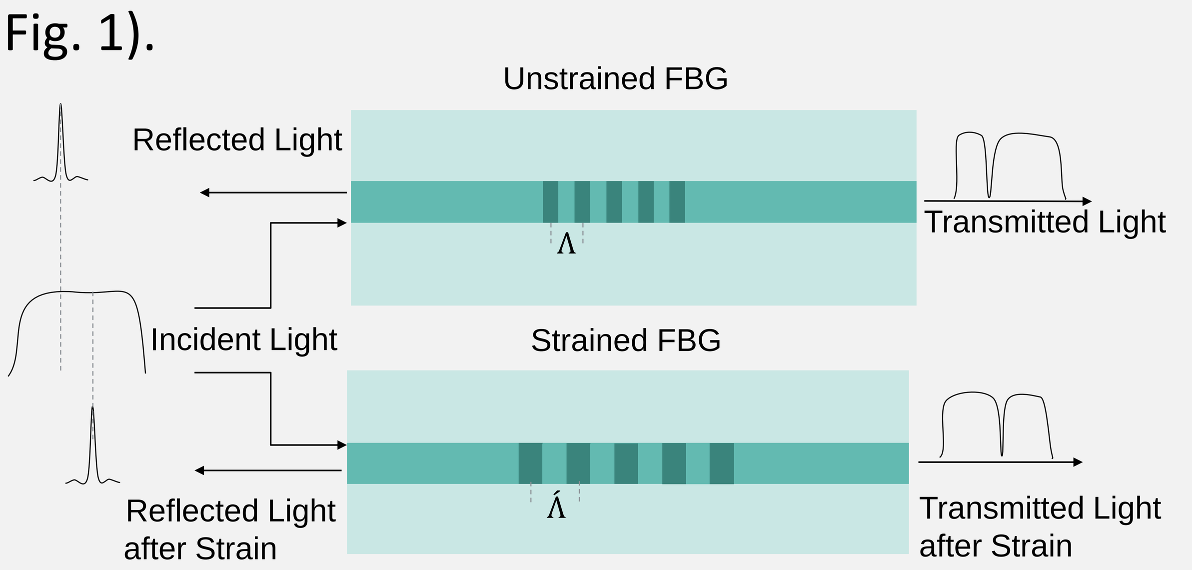

Fig. 1: Working principle of an FBG.

Method

3D-Shape Sensing:
To detect bending direction, curvature, and temperature we need three FBGs at each z-position. So that when the sensor probe is bent one of the FBGs is compressed while the other two face the tensile force (shown in Fig. 2).

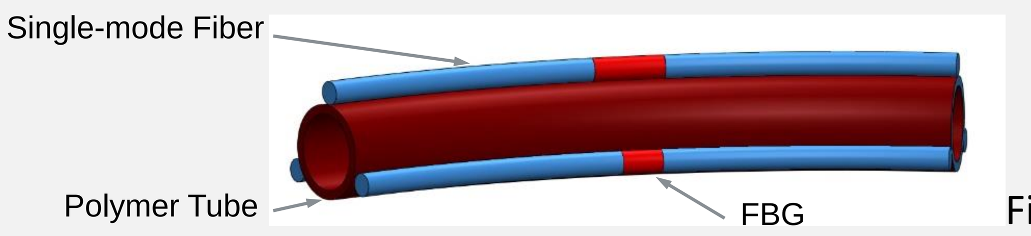

Fig. 2: Sensor probe after bending.

Curvature, Torsion and Temperature Calculation:
Fig. 3 shows the cross-section of the sensor probe. In which E_i is the strain that fiber i undergoes, θ_{ij} is the angle between the fiber i and j, and d_i is the distance between the fiber and the neutral axis. The bending angle θ, the curvature k, and the strain due to the temperature can be calculated at each z-position according to the following equation systems:

$$E_1 = E_t + kd_1 \sin\theta$$
$$E_2 = E_t + kd_2 \sin(\theta + \theta_{12})$$
$$E_3 = E_t + kd_3 \sin(\theta + \theta_{13})$$
$$E_i = \frac{1}{\alpha}\frac{\Delta\lambda_i}{\lambda_i}$$

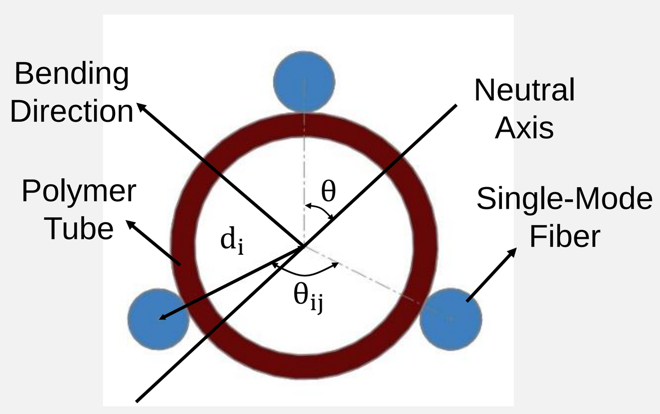

Fig. 3: Cross section of the sensor.

Once the torsion and the curvature are calculated for each FBG, the 3D shape can be reached by solving the Frenet-Serret equations.

Design & Characterization

Sensor Assembly:
We've used three single-mode fibers with 4 arrays of FBGs at different wavelengths. The FBGs are 5 cm apart and attached to a Ø1.05 mm wire-braided Polyimide tube, using a highly flexible glue.

Calibration:
To measure the angles between the fibers, the relative wavelength shift in a specific curvature is measured for different bending angles (Fig. 4). The process is repeated for different curves and is shown in Fig. 5. The slope of this calibration curve is proportional to αd_i.

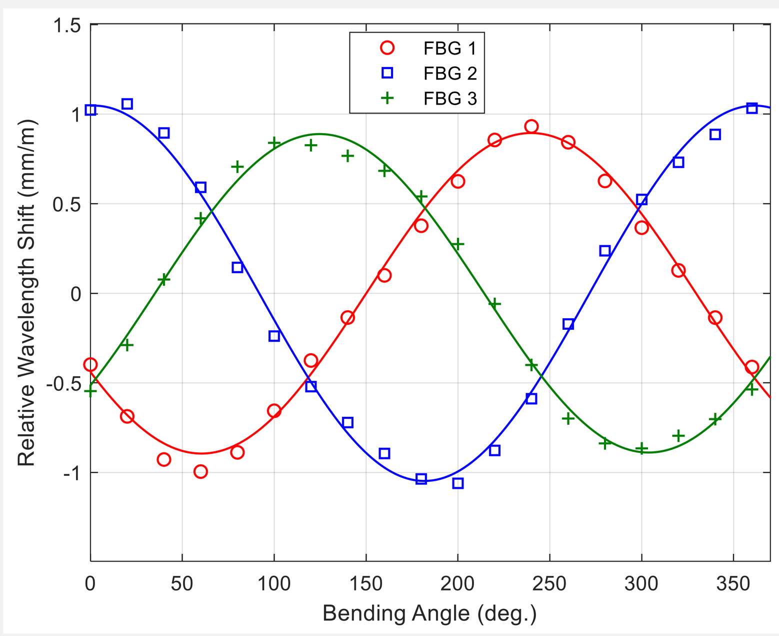

Fig. 4: The sinusoidal dependency of the relative wavelength shift to the bending direction.

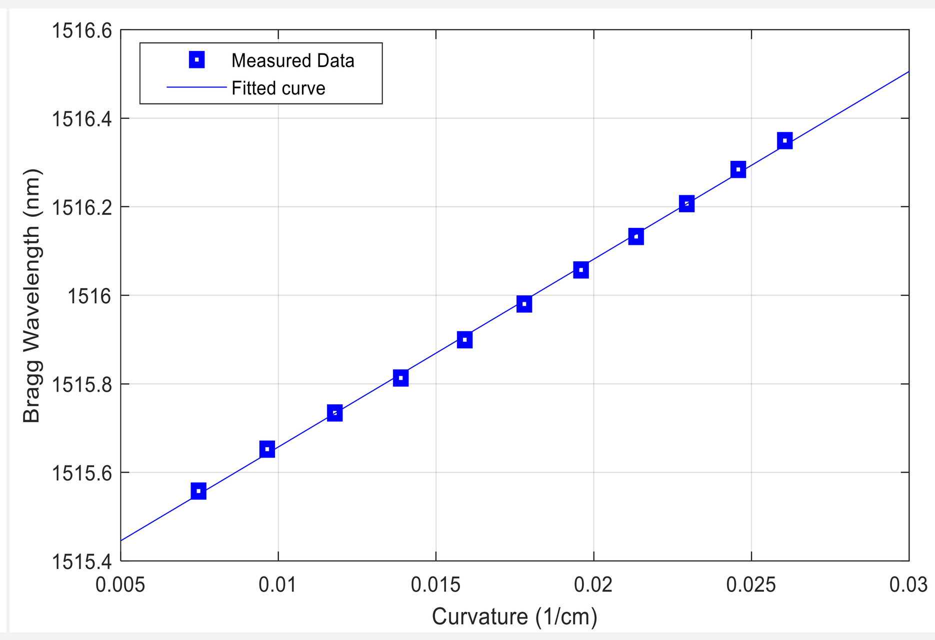

Fig. 5: The linear dependency of the relative wavelength shift to the curvature.

Results

Calibration Setup:
The sensor is held by two rotating holders, which are attached to 3D printed hinges. The inlet of the sensor in fixed while the tip is placed on a motorized linear stage (Fig. 6).

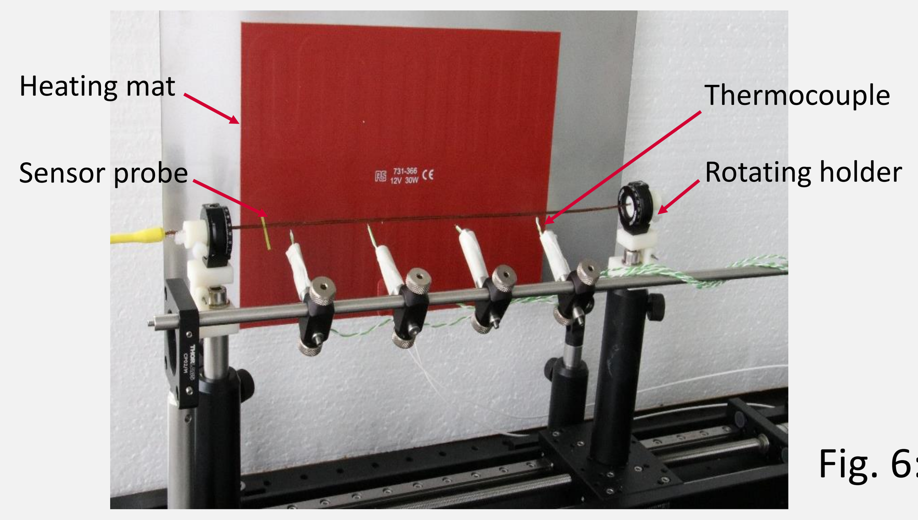

Fig. 6: The calibration setup.

Shape Reconstruction Accuracy:
The accuracy of reconstructed shape strongly depends on the calibration parameters. The average positioning error in the preliminary results is 1.4% which decreased down to 0.58% after improving the data acquisition and signal processing.

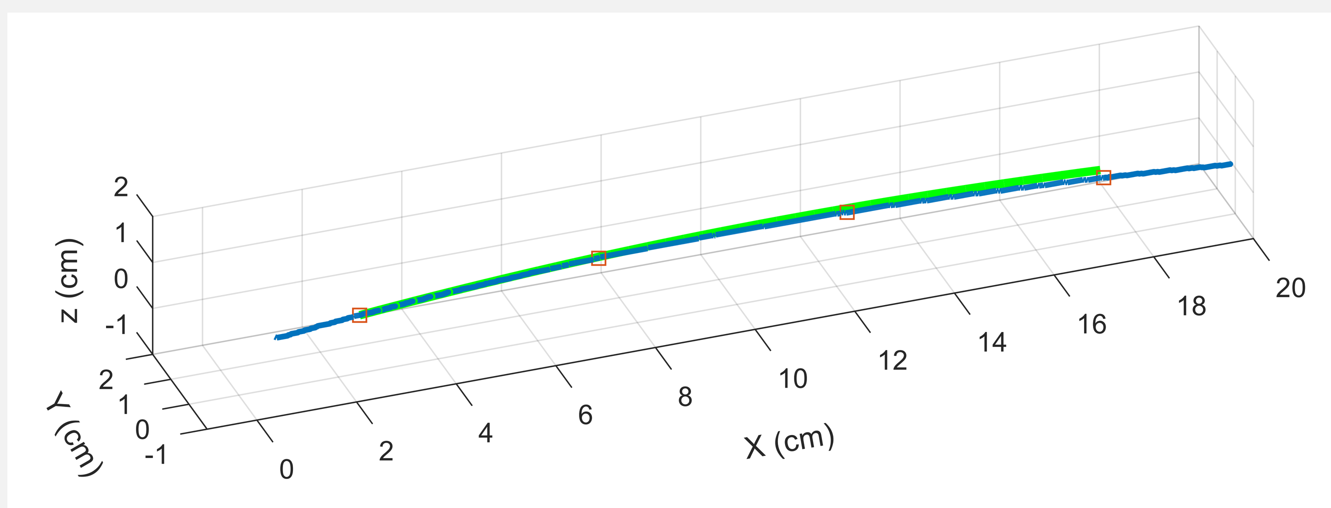

Fig. 7: The real shape (blue) and the reconstructed shape (green) of the sensor.

Future Work

In the future work, we are looking in to single mode fiber solutions in which all FBGs can be integrated. This helps to overcome some limitations due to the gluing process.

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