University of Basel
Department of Biomedical Engineering

Project MIRACLE
Planning and Navigation
CIAN

New Generation of Optical Fiber Shape Sensors

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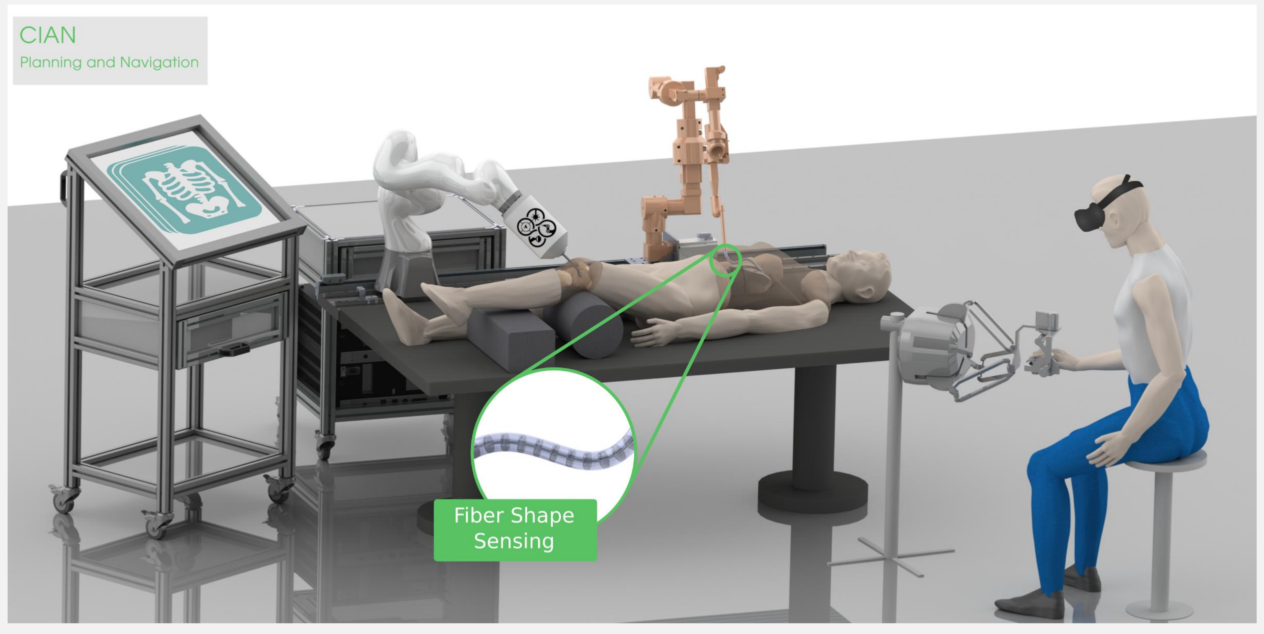
Background

Motivation

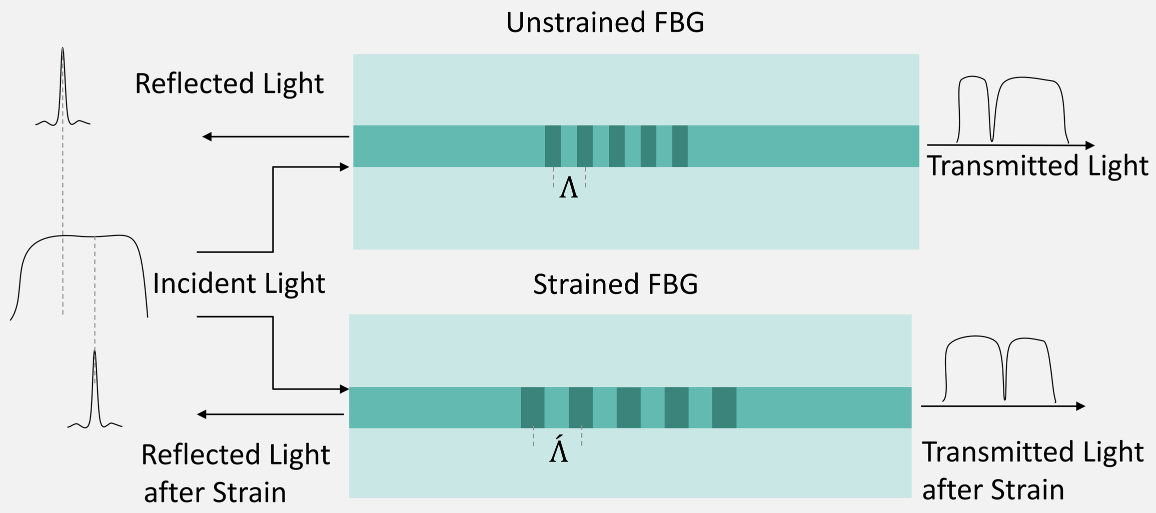
In modern medical procedures, flexible tools, catheters, and endoscopic devices are commonly used. Despite several advantages over conventional instruments, they still suffer from a lack of real-time feedback on their shape. Fiber Bragg grating(FBG)-based 3D shape sensing is a promising approach as it is small, immune to electromagnetic noise, sterile, and easy to replace.



Controlling the surgical interventions of the robotic endoscope using feedback from fiber shape senor [1].

Working Principle

FBGs are some periodic patterns of different refractive indices inside the core of an optical fiber. They show large reflectivity around Bragg wavelength, which is sensitive to mechanical and thermal perturbations.

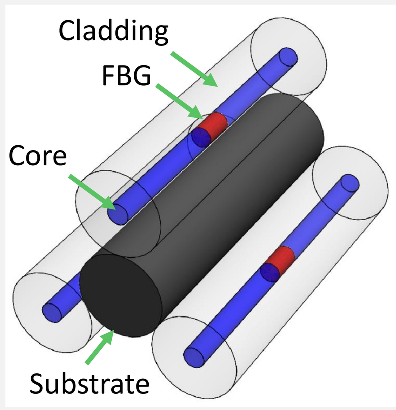


Working principle of FBGs. Mechanical or thermal strains change the period length Λ , leading to a shift in Bragg Wavelength.

Problem

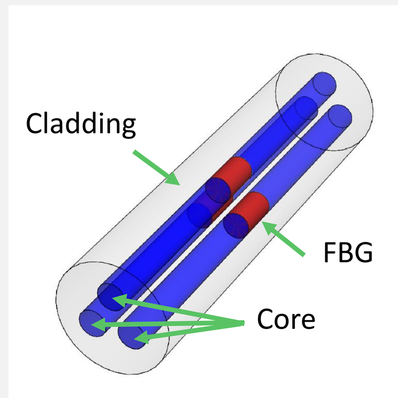
Existing shape sensing methods

Single-Mode Fibers



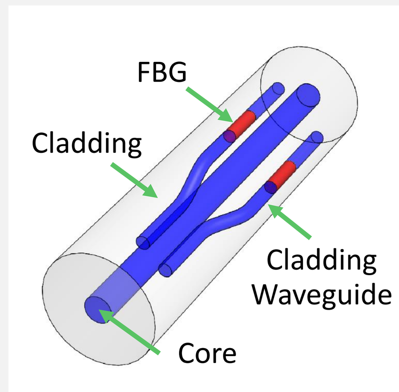
- Easy signal processing
- High sensitivity
- Low flexibility
- High thermal sensitivity

Multi-Core Fibers



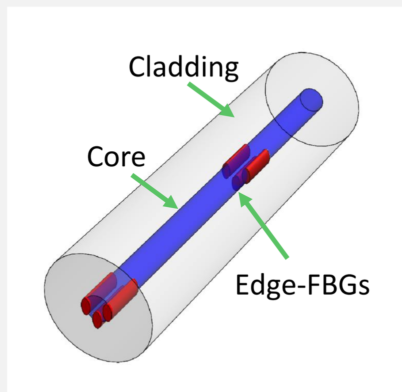
- High flexibility
- Low sensitivity
- Difficult signal processing

Cladding Waveguides



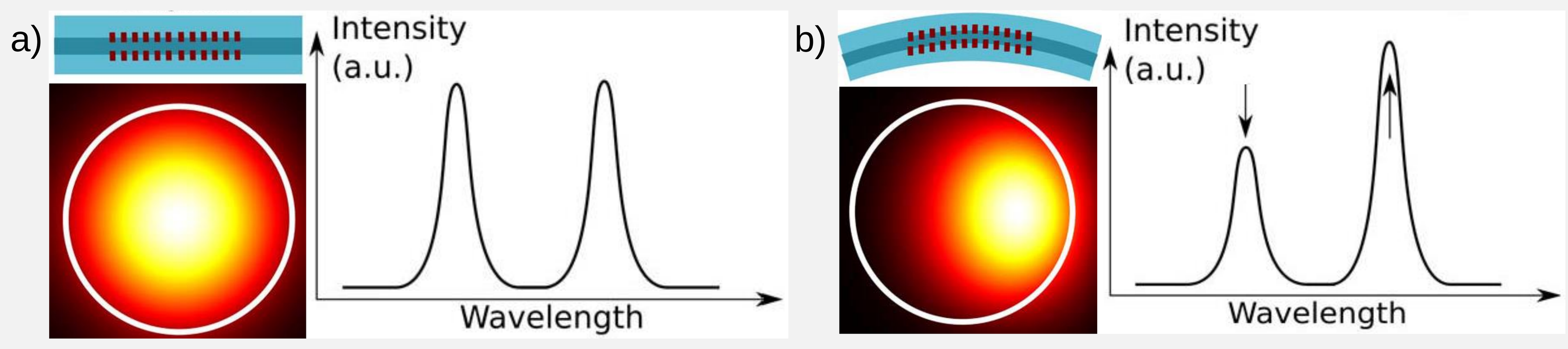
- High flexibility
- Low sensitivity
- Limited sensing points

New generation, Edge-core Fibers



- High flexibility
- Unlimited sensing points
- Simple interrogation system

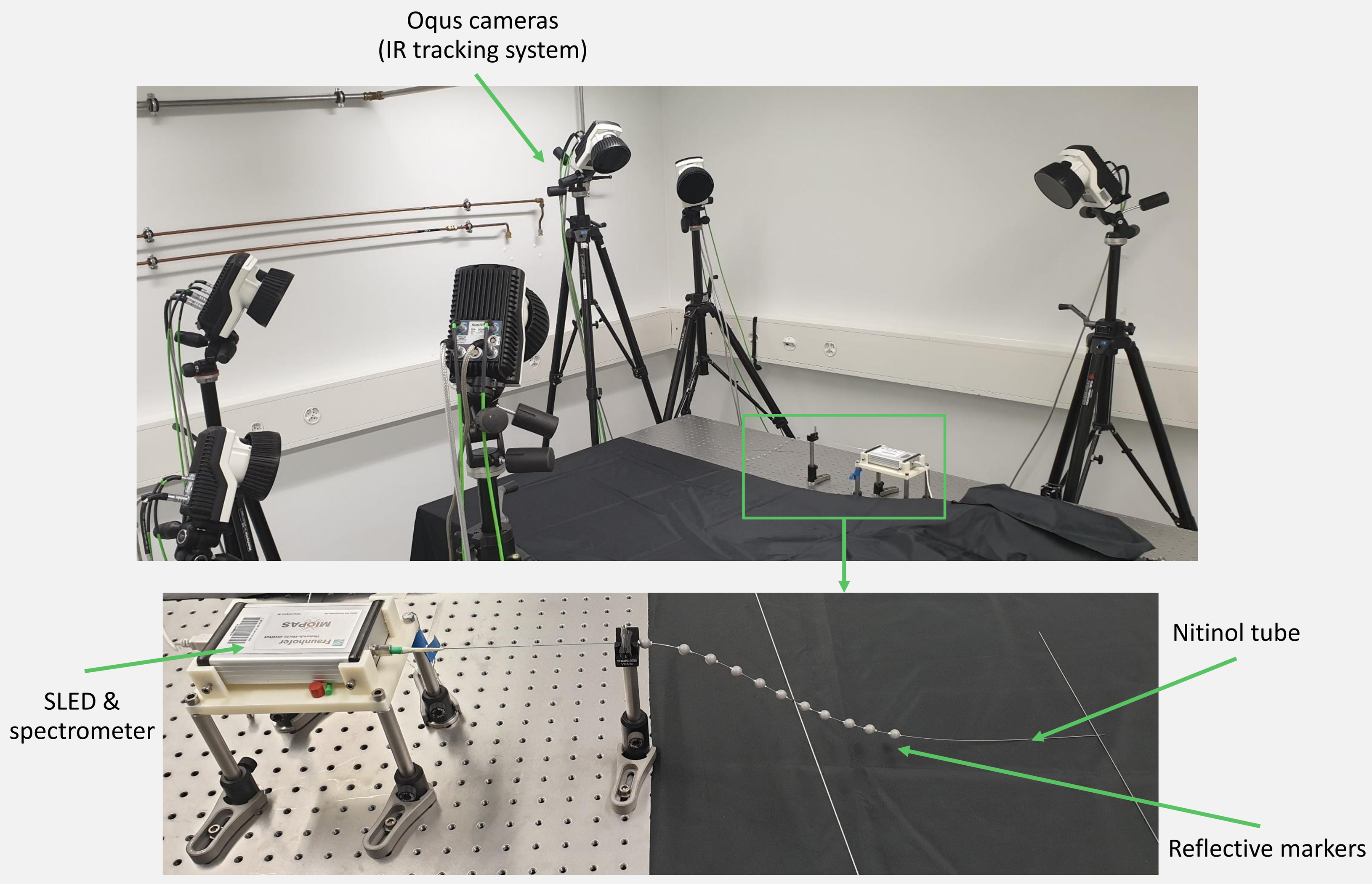
The amplitude of Edge-FBGs contains the strain information, as shown in the figure below. However, bending loss and bending-induced birefringence affect the spectrum profile, which are excluded in the mode field theory.



Working principle of Edge-FBGs. a) Mode field profile and Bragg peaks in straight fiber, b) in curved fiber [2].

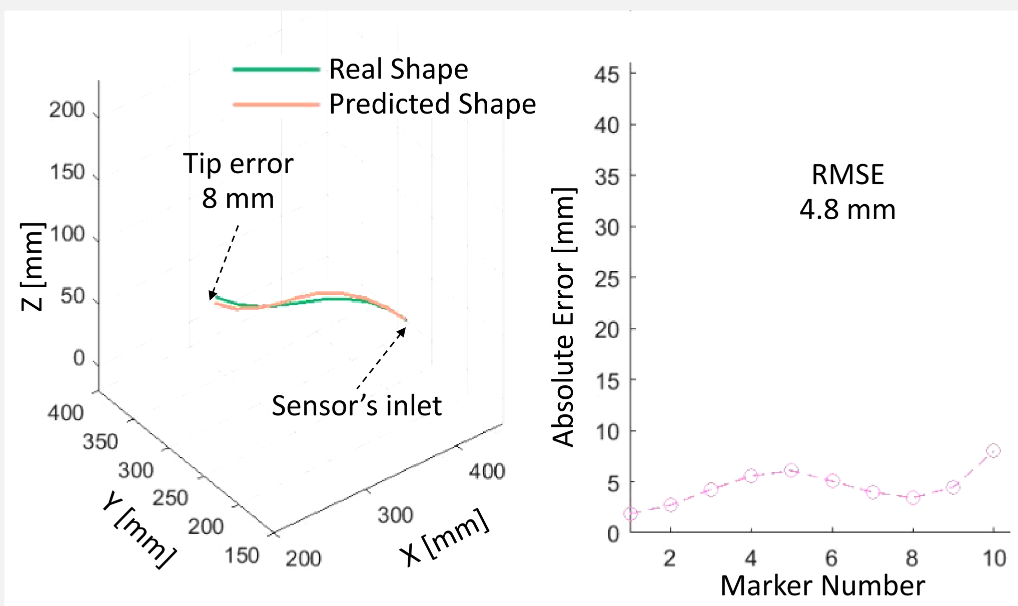
Method

Modeling the Edge-FBG sensor using deep learning



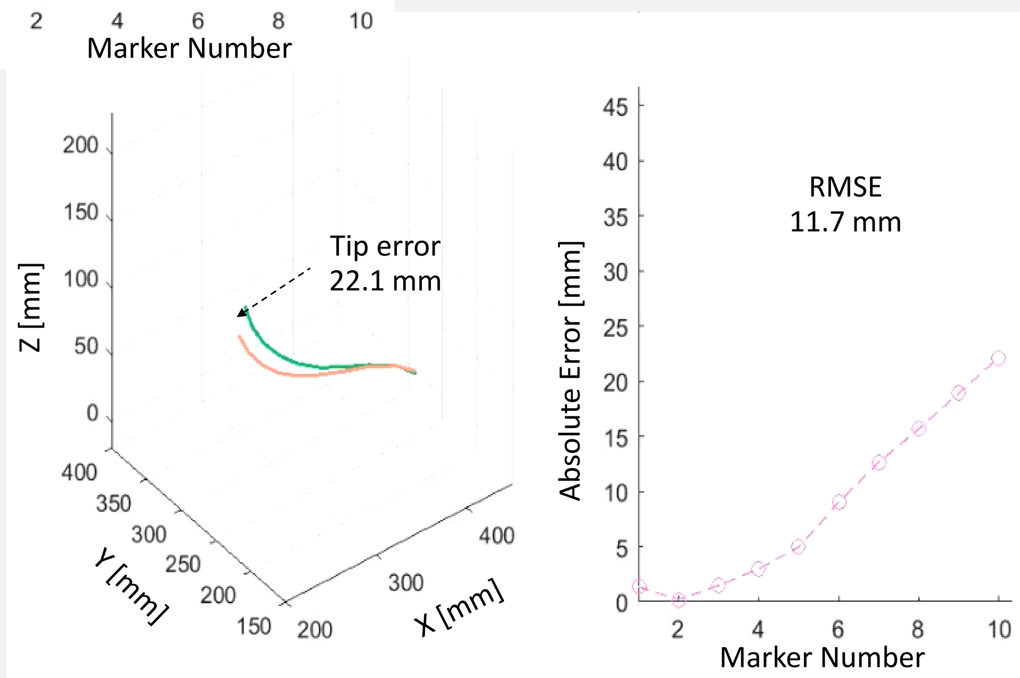
Ground truth data acquisition to train the networks.

Results



Examples of comparison between the real shape and the predicted shape. The model includes nine convolutional layers and one dense layer.

Average tip error = 17 mm
Maximum tip error = 53.5 mm
Minimum tip error = 0.8 mm



Acknowledgment

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References

[1] https://dbe.unibas.ch/en/research/laser-and-robotics/planning-navigation-622
[2] Waltermann, et al., "Multiple off-axis fiber Bragg gratings for 3D shape sensing", Applied Optics Vol. 57, No. 28, 2018.

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