FBG-based Shape Sensing Technology in Minimally Invasive Surgeries

Samaneh Manavi[1], Sara Freund[1], Philippe C. Cattin[1], Azhar Zam[2], Georg Rauter[3]

[1]CIAN, [2]BLOG, [3]BIROMED, Dept. of Biomedical Engineering, University of Basel

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. State-of-the-art tracking systems are not suitable for this task as they are sensitive to electromagnetic interference and require line of sight. Fiber-based shape sensors don't have these limitations and can accurately provide the desired positioning information.

Background

Fiber Bragg Gratings (FBG) are some periodic pattern of different refractive indices inside the core of an optical fiber. They show large reflectivity around a certain wavelength which fulfills the Bragg condition. The refractive index variations are normally induced by a UV light or femtosecond laser pulses.
External perturbation like temperature or mechanical strain can change the grating's period and therefore shift the Bragg wavelength (shown in Fig. 1).

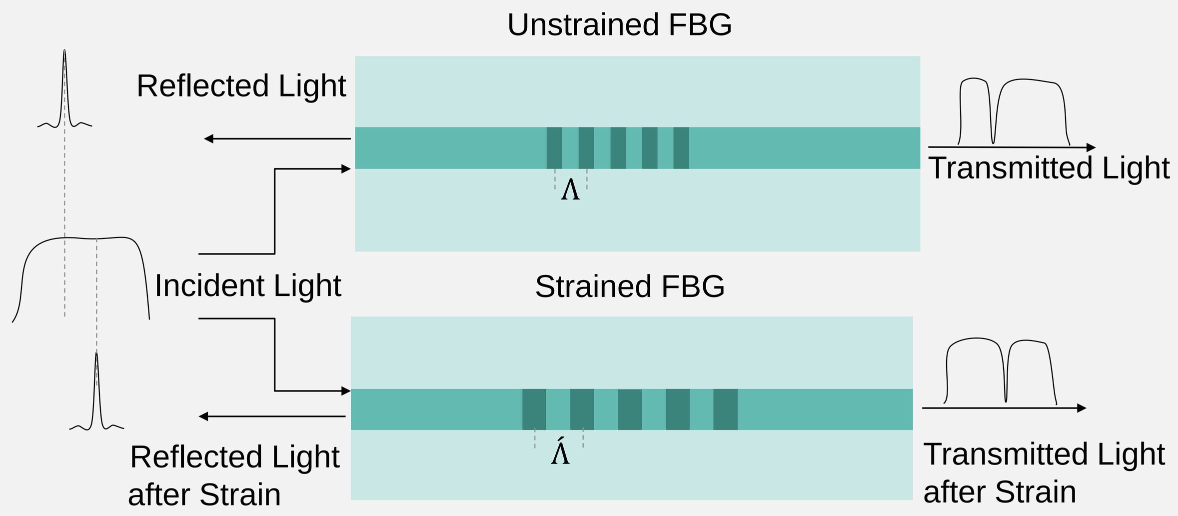

Fig. 1: Working principle of an FBG.

Existing Shape Sensing Methods

Single-Mode Fibers
- High sensitivity
- Low flexibility
- Low stability
- Easy signal processing

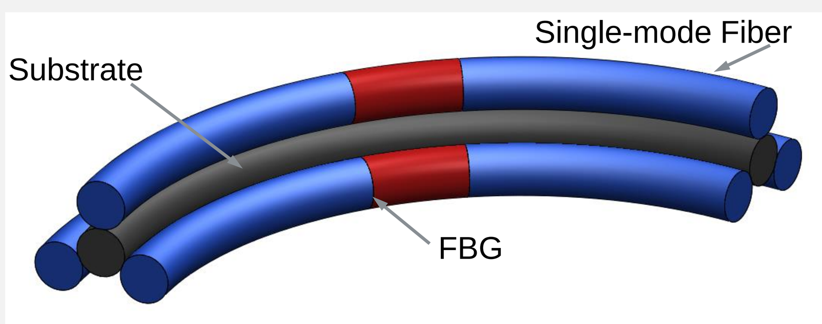

Fig. 2: Three single-mode fibers.

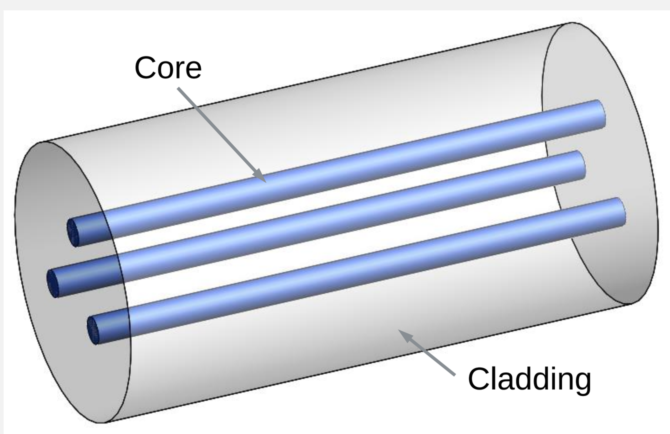

Fig. 3: Three-core fiber.

Multi-Core Fibers
- High flexibility
- Difficult signal processing
- Low sensitivity

Single-Mode Fiber with Cladding Waveguides
- High flexibility
- Low sensitivity
- Limited number of FBGs

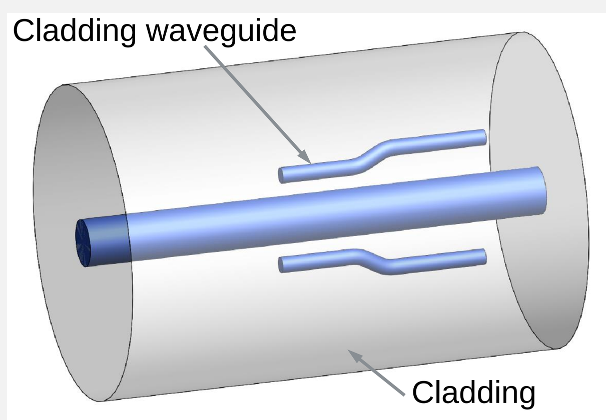

Fig. 4: Cladding waveguide FBGs.

New Generation of Shape Sensors

An innovative design for FBG-based sensors was proposed by Waltermann, et al. in 2018, where the FBGs are inscribed around the edge of the core in an optical fiber (Fig. 5). In these sensors, the strain information is extracted from the amplitude changes of the Bragg peaks (Fig. 6).

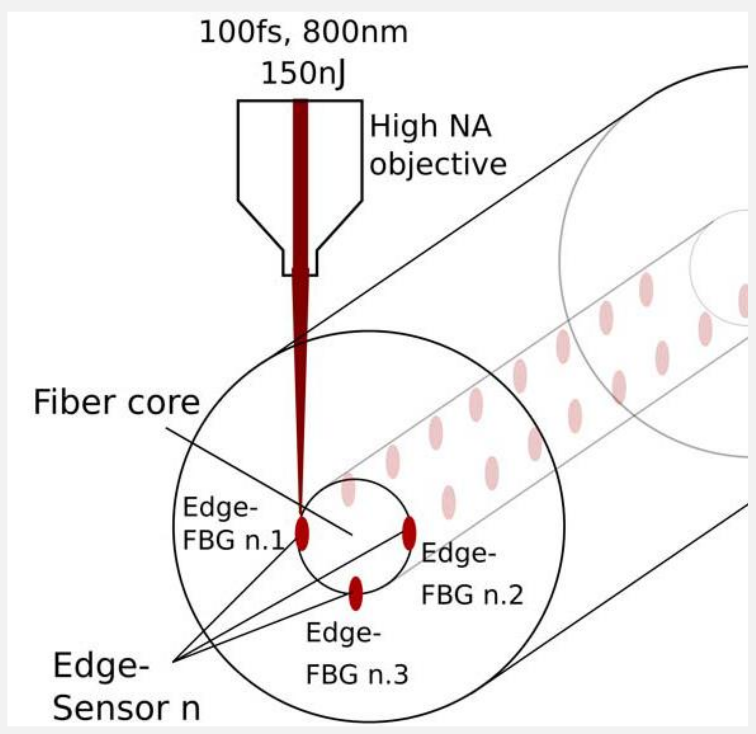

Fig. 5: Point-by-point inscription of three edge core FBGs [1].

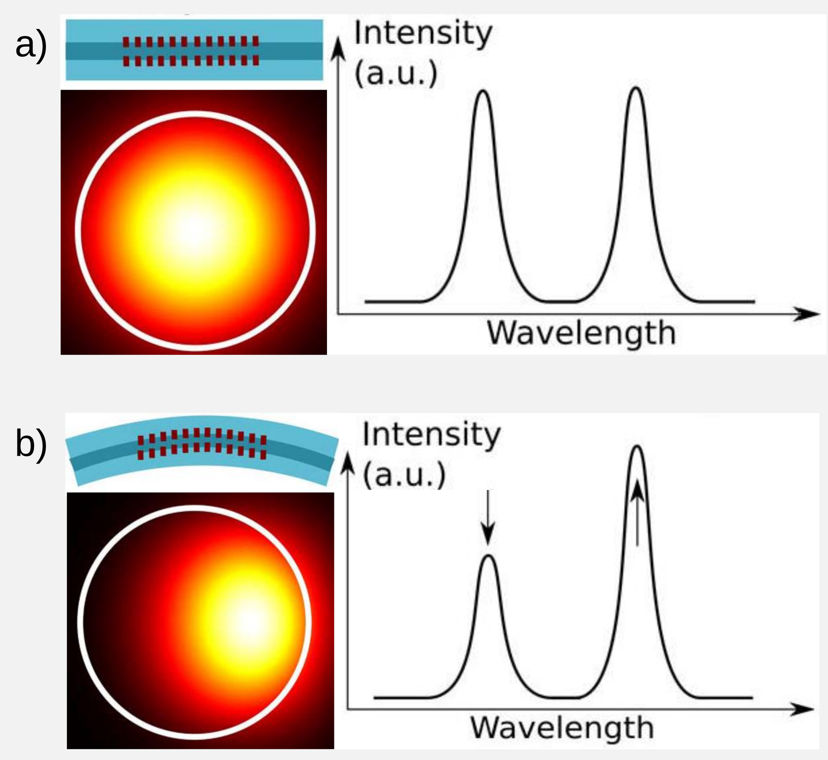

Fig. 6: a) Mode field profile and Bragg peaks in straight fiber, b) in curved fiber [1].

The main advantages of Edge-FBGs over CWG-FBGs are an unlimited number of sensors, and the use of a simple wavelength division multiplexing technique for interrogation.

Machine Learning

Although Edge-FBGs have several advantages over other FBGs, using them as shape sensor is challenging. This is because some bending related phenomena such as bending loss oscillations and bending-induced birefringence affect the spectrum profile and as a consequence change the amplitude of the Bragg wavelengths. On the other hand, the approximated mathematical models used to identify the Bragg peaks and calculate the shape of the sensor are causing a further error in the estimated shape.

Machine learning techniques have the potential to directly relate the spectrum of the reflected signal to the shape deformations and distinguish between the main signal and the error caused by bending related phenomena.

References

[1] "Multiple off-axis fiber Bragg gratings for 3D shape sensing", Waltermann, et al., Applied Optics Vol. 57, No. 28, 2018.

WSS
WERNER SIEMENS-STIFTUNG

samaneh.manavi@unibas.ch