ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/282572657

Shape Estimation for Flexible Medical Instruments – An Approach Based on FBG Sensors Embedded in a Biocompa....

Conference Paper · October 2015

CITATIONS
0

READS
121

5 authors, including:


Kumar Saurabh
Indian Institute of Science
9 PUBLICATIONS **1** CITATION

SEE PROFILE


Shanthanu Chakravarthy
Indian Institute of Science
9 PUBLICATIONS **14** CITATIONS

SEE PROFILE


G. K. Ananthasuresh
Indian Institute of Science
207 PUBLICATIONS **3,105** CITATIONS

SEE PROFILE


S. Asokan
Indian Institute of Science
298 PUBLICATIONS **2,255** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project MNCF CeNSE View project

Project Fabry Perot Cavities Based on Fiber Bragg Gratings View project

All content following this page was uploaded by Kumar Saurabh on 05 October 2015.

The user has requested enhancement of the downloaded file.

Shape Estimation for Flexible Medical Instruments

An Approach Based on FBG Sensors Embedded in a Biocompatible Polymer Filled Tube

Kumar Saurabh[1,5], Shanthanu Chakravarthy[2], G.K. Ananthasuresh[2], Amrutur Bharadwaj[3,4], Sundarrajan Asokan[1,4]

[1]Dept. of Instrumentation & Applied Physics, [2]Dept. of Mechanical Engineering, [3]Dept. of Electrical Communication Engineering,

[4]Robert Bosch Centre for Cyber Physical Systems

Indian Institute of Science, Bangalore, India

[5]Bosch Research & Technology Centre

Bangalore, India

kumar.saurabh@iap.iisc.ernet.in

***Abstract*—Real time shape estimation is important in several applications involving flexible medical instruments for minimally invasive investigations and surgery. Optical fiber sensors have been shown to be effective in this regard as compared to other methods. However, constraints arising out of bonding onto alloy substrates restrict the bending radius due to high strains and spectral distortion. Algorithms based on simple strain measurements from multiple FBG sensors to obtain exact radius of curvature impose the need for very high precision in placement. In this work, we propose a method based on Fiber Bragg Grating (FBG) sensors embedded in Polydimethylsiloxane (PDMS) placed in plastic tubing to overcome these shortcomings.**

Keywords*—*Shape Estimation; Flexible Medical Instruments; FBG Sensors; PDMS;

I. Introduction

Real time shape estimation of flexible instruments is important in building assistive systems for surgeons performing minimally invasive procedures. Limitations of methods based on fluoroscopy [1] and electromagnetic tracking [2] have been studied earlier. In this context, methods based on optical sensing and especially those based on fiber optics are interesting. Sophisticated methods involving multicore fibers [3] and Bragg waveguides in coreless fibers [4] have been proposed. However, reliance on fibers and fabrication methods that are not readily accessible and expensive interrogation methods make them difficult to deploy. The work presented here attempts to address the shape estimation problem using FBG sensor arrays fabricated using commercially popular methods while reducing complex requirements on very precise sensor placement and alignment.

II. Experiments and Results

A. FBG Sensors Bonded to Nitinol – Results and Limitations

Methods and algorithms for shape estimation by bonding FBG sensors on Nitinol (a nickel-titanium alloy) have been studied earlier especially in the context of needle guidance [5]. However, prior applications [6] to flexible instruments like endoscopes that undergo much larger bending have not considered the very high strain values and FBG spectrum distortion that lead to substantial difficulty. Also, the stiffness of the wire adversely affects the flexibility, and thus the maneuverability of the instrument. Table I shows the strains measured on a FBG sensor bonded on a nitinol wire of diameter 1.2mm. For radius of curvatures below 120 mm, the strains are very high and often lead to sensor breakage.

TABLE I: Strain on FBG sensors bonded to a nitinol wire of diameter 1.2mm for different radius of curvatures

Radius of curvature (mm)	164	154	141	130	120	108	96	81
Measured Strain (μstrain)	3800	4100	4600	4800	5100	5800	6300	6700

B. Embedded FBG sensors

One of the major advantages of FBG sensors is that they can be embedded inside other materials. In the method proposed here, FBG sensors fabricated using phase mask method using 125 micron germanosilicate optical fibers were placed inside a medical grade plastic tube used for intravenous injections and then the tube was filled with Polydimethylsiloxane (PDMS) and allowed to cure. PDMS provides the dual advantage of high flexibility and biocompatibility. It was ensured that the sensors are apart by more than 60º but no specific constraint was put on the angle as it is difficult to place multiple sensors with exactly the same angle between them. Furthermore, no specific constraint to have a perfectly straight tube after the curing process is imposed.

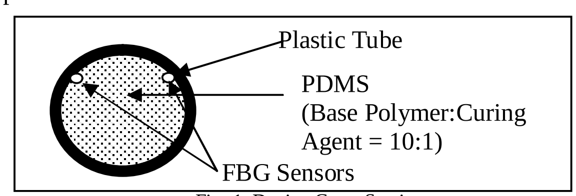


Fig. 1. Device Cross Section

A calibration phase was performed consisting of measuring FBG peak wavelength for different radii of curvature ranging from 15cm to 3 cm and at six different

This work has been funded by Robert Bosch Centre for Cyber Physical Systems, Indian Institute of Science, Bangalore, India.

positions of the sensors relative to the neutral axis of the tube. The device was inserted into another tube with a uniform curvature as shown in Fig 2.

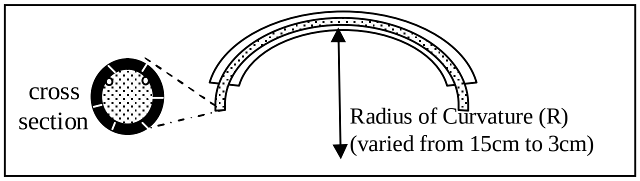


Fig. 2. Experimental Setup for calibration

Fig. 3 shows the plots of measured Bragg peak wavelength for different radii of curvature at two different rotation positions inside the larger tube.

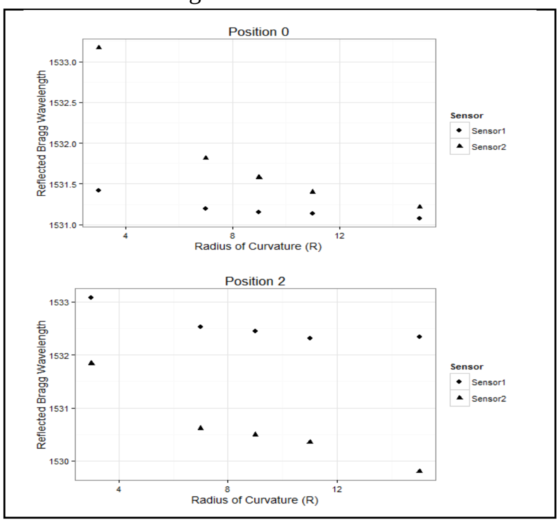


Fig. 3. Reflected Bragg Wavelength at different R values

The nonlinear relation between the radius of curvature, position of the sensors relative to the neutral axis and the reflected wavelength shift can be seen in Fig. 3. Multi Layer Artificial Neural Networks (ANNs) are good at learning such non linear relations. Hence, an ANN with two hidden layers was trained using the statistical computing software '*R*' to perform non linear regression to estimate the radius of curvature from the delta Bragg wavelengths that correspond to strain. Only 30% of data was used for training while the rest 70% was used as test set to ensure good generalization over the different positions. The estimation errors for test positions are shown in Fig 4.

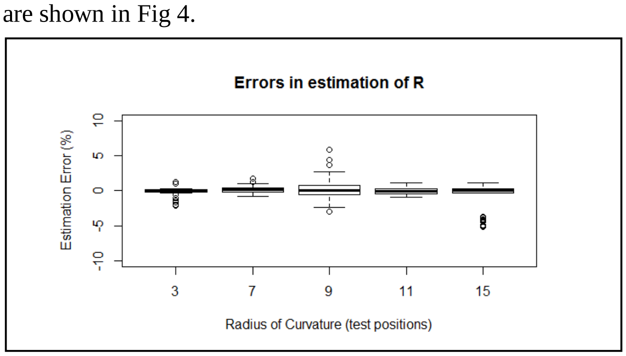
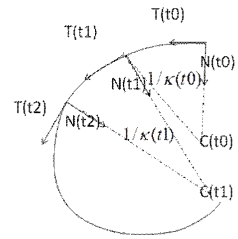


Fig. 4. Estimation errors for test positions by the trained ANN

A 2D curve can be built from small segments using Frenet-Serret equations and the algorithm mentioned below which is explained in detail in [7]. The curvature κ can be obtained from the estimated radius of curvature R.

$$\begin{bmatrix} \dot{T} \\ \dot{N} \\ \dot{B} \end{bmatrix} = \begin{bmatrix} 0 & \kappa(t) & 0 \\ -\kappa(t) & 0 & \tau(t) \\ 0 & \tau(t) & 0 \end{bmatrix} \begin{bmatrix} T(t) \\ N(t) \\ B(t) \end{bmatrix}$$



Given **x**(0), **T**(0) and **N**(0) and v(t) and k(t), in some range 0 ≦ t ≦t* such that k(t) ≠0 in the range, define h=t*/N for some large N. Defining $\mathbf{x_h}(0)=\mathbf{x}(0)$, for 0 ≦ j<N

$$Centre \quad C_j = x_h(t_j) + \frac{1}{k(t_j)} N_j$$

$$x_h(t) = C_j + \frac{1}{k(t_j)} \left[\left[-\cos\left(k(t_j)v(t_j)(t-t_j)\right)N_j\right] + \left[\sin\left(k(t_j)v(t_j)(t-t_j)\right)T_j\right]\right]$$

$$T_{j+1} = \sin\left(k(t_j)v(t_j)h\right)N_j + \cos\left(k(t_j)v(t_j)h\right)T_j$$

$$N_{j+1} = \cos\left(k(t_j)v(t_j)h\right)N_j - \sin\left(k(t_j)v(t_j)h\right)T_j$$

III. Future Work

It is proposed to create a more robust calibration step for a complete sensor array. Also the 3D shape reconstruction used for an earlier setup utilizing strain gauges [8] will be applied to the FBG setup.

References

[1] D.G. Adler, "The Role of Fluoroscopy in the Endoscopic Management of Luminal Gastrointestinal Disorders," Techniques in Gastrointestinal Endoscopy, 2007, Vol 9, pp. 189-194.

[2] L.Y. Ching, K. Moeller and J. Suthakorn, "Non radiological colonoscope tracking: Image guided colonoscopy using commercially available electromagnetic tracking system", IEEE Conference on Robotics, Automation and Mechatronics, 2010.

[3] J.P. Moore and M.D. Rogge, "Shape sensing using multi-core fiber optic cable and parametric curve fitting," Optics Express, 2012, Vol 20 , pp. 2967-2973

[4] Kenneth K.C. Lee, A. Mariampillai, M. Haque, B.A. Standish, Victor X.D. Yang and Peter R. Harman, "Temperature compensated fiber-optic 3D shape sensor based on femtosecond laser direct-written Bragg grating waveguides," Optics Express, 2013, Vol 21, pp. 24076-24086

[5] R.J. Roesthius, M. Kemp, J.J. van den Dobbelsteen and S. Misra, "Three-dimensional needle shape reconstruction using an array of fiber bragg grating sensors," IEEE/ASME Transactions on Mechatronics,2014, Vol 19, pp. 115-1126

[6] Xinhua Yi, Jinwu Qian, Linyong Shen, Yanan Zhang and Zhen Zhang, "An innovative 3D colonoscope shape sensing sensor based on FBG sensor array," in Proceedings of the 2007 International Conference on Information Acquisition, 2007.

[7] Eric A. Carlen, "Multivariable Calculus, Linear Algebra and Differential Equations," September 2013

[8] Ananya, S. Chakravarthy, K. Saurabh and G.K. Ananthasuresh, "Shape Estimation and Prediction of Locations of the Force on a Flexible Tube using Strains at a Few Points," 2nd International and 17th National Conference on Machines and Mechanisms, iNaCoMM, 2015, Submitted

View publication stats