Simultaneous Shape Reconstruction and Force Estimation of Soft Bending Actuators Using Distributed Inductive Curvature Sensors

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Introduction

Motivation:

1. Soft robots are extensively studied in exploring unknown environments and grasping delicate objects, because of their intrinsic compliance and safe human-robot interaction.
2. Unlike traditional rigid robots that are typically equipped with reliable sensors, soft robots face challenges in perception due to their infinite degrees of freedom.
3. Proprioceptive: High-accuracy continuous shape sensing is important for obstacle avoidance and position control.
4. Exteroceptive (Intrinsic force sensing): It is crucial for soft robots to estimate external forces without exterior sensors when interacting with the environment in applications such as minimally invasive surgery.

Objective:
In this work, we present, to the best of our knowledge, the first multimodal perception system for soft robots, encompassing not only continuous shape proprioception but also accurate intrinsic force sensing.

Distributed Inductive Curvature Sensors

- A novel distributed inductive curvature sensor for real-time monitoring of the shape of soft bending actuators.
- The fabrication of the proposed sensor (FPCB) is easily implementable and scalable for various bending actuators.

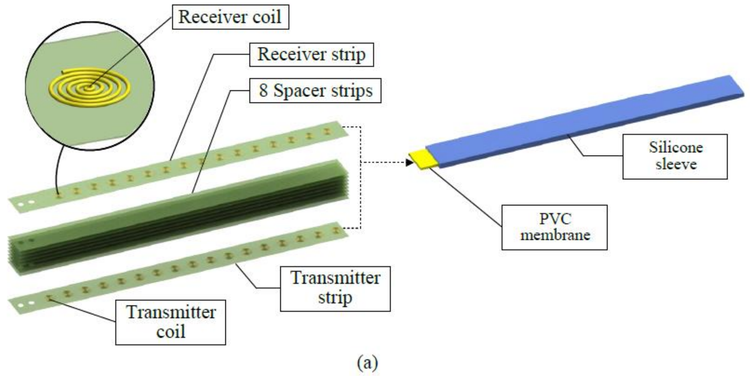


Fig. 1. Illustration of the proposed curvature sensor. (a) Components and assembly layout of the sensor; (b) an assembled prototype.

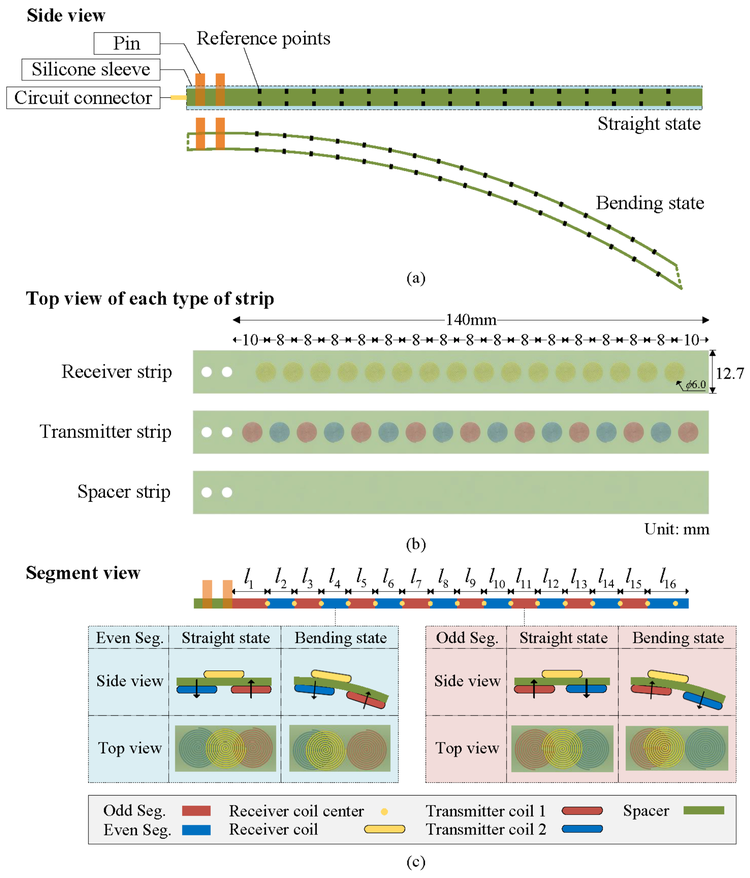


Fig. 2. Design and concept of the distributed inductive curvature sensor.

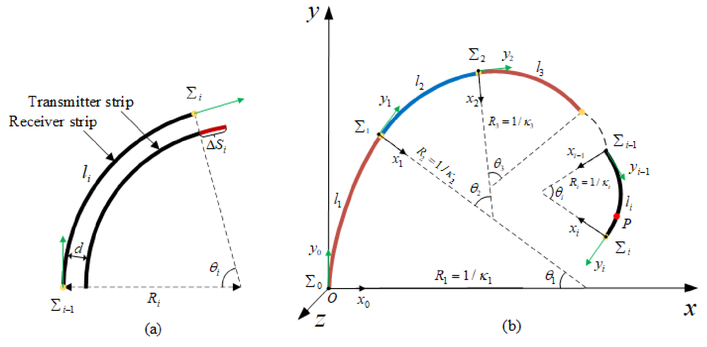
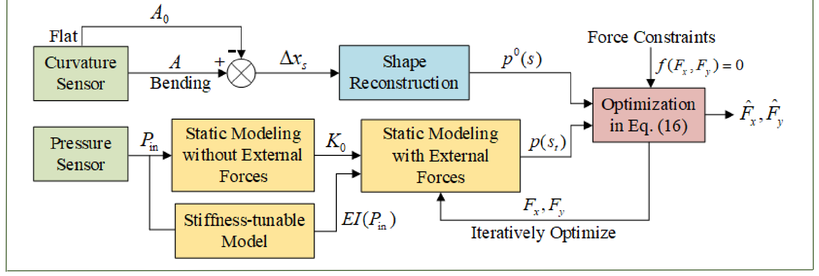


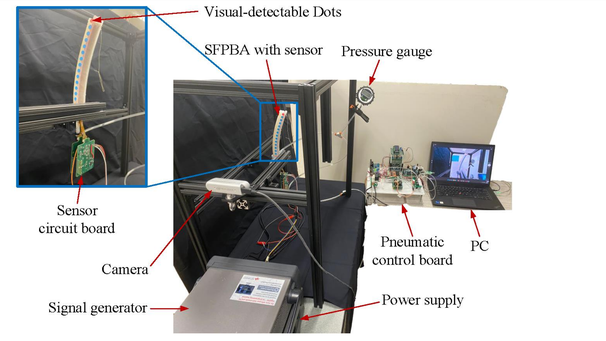
Fig. 3. Piecewise constant curvature kinematic model.

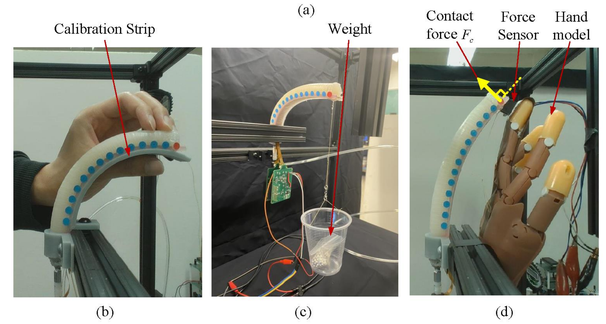
Model-based Force Estimation Algorithm

- Analytical models based on Euler-Bernoulli beam theory.



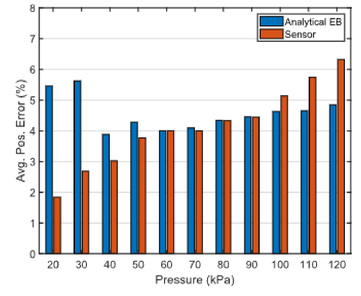
Experiments and Results

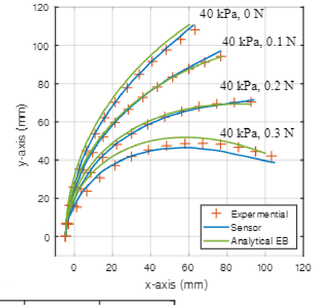


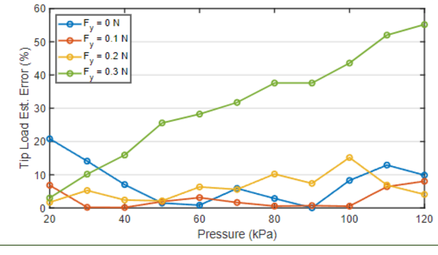


Extensive experiment results:

a) Both sensor measurements and analytical modeling accurately predict the shape within a relative error of 6 %.
b) The error of force estimation algorithm is within 5.49 %, when the load is 0-0.2 N.







Demo Video:

SCAN ME

Reference

[1] **Y. Mei**, L. Peng, H. Shi, X. Qi, Y. Deng, V. Srivastava and X. Tan, "Simultaneous Shape Reconstruction and Force Estimation of Soft Bending Actuators Using Distributed Inductive Curvature Sensors," *IEEE/ASME Transactions on Mechatronics*, 2024.

Acknowledgements

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