Design and analysis of a soft contiuum robot for endoscopy

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Abstract

The abstract goes here.

Index Terms

IEEEtran, journal, LaTeX, paper, template.

I. Figures and Tables

1) Figure of our prototype
   - to give first impression what this paper is about
   - in the introduction section
   - with working channel and biopsy forceps
   - with camera and LED
   - endoscopic view with biopsy forceps
   - photo of ex-vivo experiments
2) Tables
   - to show the need of soft robotic endoscope
   - in the introduction section
   - state-of-the-art robotic endoscope
     - size
     - actuation method
     - materials
3) Table of hyperelastic models:
   - in methodology section
   - several candidates
   - equations of the corresponding strain-energy functions
4) Figure of FEM models
   - in methodology section
   - to show more details about the FEM meshing techniques
   - 2D cross-sectional design
     - indicate the design parameters
   - show the meshed figures
     - indicate different types of elements
       - hexahedral, truss elements
5) Table of the FEM parameters
   - in methodology section
   - to show more details about the FEM simulation
   - the simulation parameters and the corresponding values for each hyperelastic model
     - e.g. name of the software
     - e.g. the number of elements used for simulation
     - e.g. name of the element in the software
   - (fitting error, which indicates the best candidate among the hyperelastic models)
6) Figures of fabrication procedure
   - photos or schematic diagram
7) Figures of FEA results
   - objective: the design parameters are optimized based on these FEA results
   - stress vs strain

  - to show how high stress the endoscope can sustain before failure
  - longitudinal and axial direction
- pressure vs elongation
  - to show the change of the scope length during bending
  - if the change is small, this figure can be omitted. instead describe this data in the text
  - double channel actuation
  - curves of different design parameters
  - (with and without instrument)
- pressure vs bending performance
  - to show the bending curvature at different pressure
  - ratio between the bending radius and the length of scope
  - curves of different design parameters
  - with and without instrument inserted
- can we simulate the force? e.g. the force at the tip
  - which can show the scope can provide enough force

8) Figures of real robots
   - in the result section
   - to show the actual bending behavior and the bending force of the robot
   - to show the measurement setting
   - for validation of the FEA result
9) Videos of FEA
   a) animation of bending
      - with and without instrument
   b) animation of instrument insertion
10) Videos of real robot motion
    a) bending behavior alongside of FEM animation
       i) without instrument
       ii) with instrument
    b) lifting
       - lifting a mass
       - showing the pressure sensor value alongside
    c) endoscopic view
       - working with biopsy, suction of liquid

II. Introduction

- 1st paragraph: To introduce the advantages of using soft robots in endoscopy
  - Clinical data of endoscopy, showing the increasing need of robotic endoscope
  - Review of some state-of-the-art robot-assisted endoscopy with rigid structure
    - tendon-driven
  - Current applications of soft robots in medical applications
  - Advantages of using soft robots in endoscopy
    - low-cost
      - disposable
    - easy to fabricate
    - particularly fluidically-driven soft continuum robots
- 2nd paragraph: To introduce the technical challenges of using soft robots in endoscopy
  - State-of-the-art soft robotic technologies
    - achievements in literature
  - requirements for endoscopy
    - safe
    - fast response
    - small size
    - with working channel *

    - (with embedded camera)
  - the technical challenges in design:
    - choice of material
    - structural and geometrical design
    - how stiff should be enough?
    - simulation of hyper-elastic materials and interaction with internal instrument
- 3rd paragraph: How do we solve these challenges
  - state-of-the-art FEA for hyperelastic material
    - achievement in literature
  - what are the contributions of our FEA?
    - any literature have done simulation of interaction with internal instrument?
    -
  - what are our approach/tricks that can approximate the hyperelastic behaviour?
    - new FEM formulations?
    - new combination of element?
    - optimized for fast computation?
    - etc…
  - how the FEA results be incorporate in the design optimization
    - description of role of FEA in the design optimization cycle
- 4rd paragraph: Clearly list out the contributions using the proposed FEM-based design
  - how small the soft endoscope with working channel can we achieve?
  - how much force does our prototype can it give?
  - how accurate the FEA simulations were?
  -

III. Materials and methods

A. *Design and performance requirements*

- preserve a working channel
  - for biopsy, suction, irrigation, …
  - common dimension of clinically-used biopsy forceps
    - e.g. colonoscopy,
  - requirement for the diameter: the larger the better suction
    - do we need to specify the target application, e.g. to colonoscopy?
    - but we need to specify the dimension we are using in this paper
- Dimension: Outer diameter and length
  - give examples of potential endoscopic applications
  -
- Stiffness
  - sufficient to withstand instrument insertion
  - sufficient to withstand high input pressure
- constrained elongation
  - i.e. only bending without much elongation
  - camera is mount at the tip. bending with large elongation will cause loss of tracked vision target in the endoscopic view
- Bending force
  - high enough bending force
- actuation method - fluidic actuation
  - advantages of fluidically driven - can be only Hydraulic/pneumatic
  - safe without internal electric component
  - hydraulic: incompressible transmission media gives fast response, …
  - pneumatic: ease of assembly, …
  - MRI-compatible
- Durability

  - long life cycle
- discuss difficulties of miniaturization
  - link to the proposed structural design in the next section
- figures
  - can be the same figure in the introduction section
  - a real prototype (with instrument inserted)
  - a endoscopic view

B. Structural design

- we can first give the design using fan-shaped actuation chambers
- then use FEM to demonstrate the weak points at the chamber corners
- then provide the dump bell shaped design
- actuation chamber design - 1st version: the fan-shaped
  - number of chambers
    - 3-chamber are commonly used in the literature
  - chamber geometry
    - why using the fan-shaped chamber?
  - chamber arrangement/location
- constraint layers
  - material
  - where are the constraint layers
  - what are the benefits of the constraint layers?
  - why they are necessary?
- dimension of the working channel
- which design parameters will be determined based on FEA?

C. FEM optimization

- the advanced formulations for simulating hyperelastic materials
  - how to choose the strain energy functions?
    - list several candidates, and then discuss how to choose among them.
  - what software you are using?
  - how to choose the finite element? and why?
    - hexahedral element for the hyperelastic material, truss for the constraint layer?
      - with the element number in that software (e.g. Abaqus element type C3D10H)
    - what is the number of element
    - simulation time
- how to simulate the insertion of instrument?
  - how to model the reaction force from the instrument
  - applying a force to the inner wall of the working channel
    - stiffness = force / displacement
- measuring bending performance: ratio = curvature/length
- bending force
  - what is bending force? the force at the tip ?
  -

D. Fabrication

- Fabrication process
  - low-cost
  - basic procedure (of course some basic tricks that can be disclosed)
    - e.g. sequence of molding and filling material, temperature
    - photos/schematic diagrams of the procedure. e.g. the Fig.1 in martinez2012robotic [1].
  - what should be paid attention to? why?
    - e.g. temperature control, material filling speed, assembly cautions
    - ...

IV. Results and discussion

- Comparison of the results between FEA and the real robot
- comparison to results in literature
- discuss some advantages in the endoscopy procedure

A. *Experiment setup*

- workspace analysis
  - using random pressure inputs
- how to measure the bending force
- how to measure the internal force
- fatigue test
  - no. of cycle until failure
- can take reference from yap2016highforce [2]

V. Conclusion

- summary
- future work

References

[1] R. V. Martinez, J. L. Branch, C. R. Fish, L. Jin, R. F. Shepherd, R. M. D. Nunes, Z. Suo, and G. M. Whitesides, "Robotic tentacles with three-dimensional mobility based on flexible elastomers," *Advanced Materials*, vol. 25, no. 2, p. 205212, Sep 2012. [Online]. Available: http://dx.doi.org/10.1002/adma.201203002

[2] H. K. Yap, H. Y. Ng, and C.-H. Yeow, "High-force soft printable pneumatics for soft robotic applications," *Soft Robotics*, vol. 3, no. 3, p. 144158, Sep 2016. [Online]. Available: http://dx.doi.org/10.1089/soro.2016.0030