A soft continuum robot prototype for endoscopy

Author 1, Author 2

# 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
     + can be a screenshot inside the (phantom) colon
2. 2D FEA
   * to compare the fan-shaped and the dump-bell-shaped design
   * 2D cross-sectional design
   * showing high stress found at the chamber corners and the wall between the working channel
   * in methodology section
3. Stress-strain curves of the whole bendable section
   * curves of different materials
   * for the choice of FEA formulation (curve fitting)
   * as rationale for the choice of material
   * to show how high stress the endoscope can sustain before failure
   * longitudinal, transverse direction
4. Table of hyperelastic models:
   * in methodology section
   * several candidates
   * equations of the corresponding strain-energy functions
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. FEA results - bending curvature vs pressure
   * to show the bending behaviour of the scope
   * curvature ratio = radius/length
   * conditions
     + bending when actuating 1 and 2 chambers
     + different preloaded pressure
     + different designs (e.g. chamber cross-section area)
   * also the real robot data
7. FEA results - min. force to displace the tip vs curvature ratio
   * to show the stiffness of the scope
   * force perpendicularly exerted to the tip (center of the cross section)
   * condition
     + actuating 1 and 2 chambers
     + curves of different preloaded pressure
     + different designs
   * also the real robot data
8. Figures of the robot prototype
   * to show basic functions of the prototype
   * robots with camera, working channel and LED
   * show together with the endoscopic view
   * photo with biopsy forceps inserted
   * photo of irrigating water
   * photo of sucking water
   * photo of lifting a mass
   * these photos can be the snapshots of videos
9. Figures of the real robots bending behavior and tip force
   * robots with camera, working channel and LED
   * to show the actual bending behavior and the stiffness of the prototype
   * to show the measurement setting
   * alongside with the FEA figures
10. (Figures of fabrication procedure)
    * photos or schematic diagram
    * sequence of fabrication

* molding
* the material pouring sequence
* temperature condition

1. Videos of FEA
   1. animation of bending
   2. animation of adding force at the tip
2. Videos of real robot motion
   1. bending behavior alongside of FEM animation
   2. lifting a mass
   3. endoscopic view
   * working with biopsy, suction of liquid

# 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?

# Materials and methods

## 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

## 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 do we use the fan-shaped chamber?
  + chamber arrangement/location
    - mention about
* 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?

## 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 ?

## 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](papers:Robotic Tentacles with Three-Dimensional Mobility Based on Flexible Elastomers) Martinez et al. (2012).
  + what should be paid attention to? why?
    - e.g. temperature control, material filling speed, assembly cautions
    - ...

# 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

## 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](papers:High-Force Soft Printable Pneumatics for Soft Robotic Applications) Yap, Ng, and Yeow (2016)

# Conclusion

* summary
* future work

Martinez, Ramses V., Jamie L. Branch, Carina R. Fish, Lihua Jin, Robert F. Shepherd, Rui M. D. Nunes, Zhigang Suo, and George M. Whitesides. 2012. “Robotic Tentacles with Three-Dimensional Mobility Based on Flexible Elastomers.” *Advanced Materials* 25 (2). Wiley-Blackwell: 205–12. doi:[10.1002/adma.201203002](https://doi.org/10.1002/adma.201203002).

Yap, Hong Kai, Hui Yong Ng, and Chen-Hua Yeow. 2016. “High-Force Soft Printable Pneumatics for Soft Robotic Applications.” *Soft Robotics* 3 (3). Mary Ann Liebert Inc: 144–58. doi:[10.1089/soro.2016.0030](https://doi.org/10.1089/soro.2016.0030).