Visual-based Model-free Control of Soft Continuum Robot for Effective Endoscopic Navigation

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# Introduction

* why soft continuum robots suit for manipulating the camera in laparoscopic surgery
  + the role of camera in laparoscopic surgery
    - what is the common location?
    - how the camera is manipulated during the surgery?
  + fluidically-driven soft continuum robot
  + compliant, safe
  + disposable
  + high DOF, can
* any application have been done using soft robot in laparoscopic surgery?
  + seems no
  + any application of flexible endoscope in laparoscopic surgery
* why visual-based feedback?
  + difficulty of miniaturization while installing other tethered positional sensors
    - reliable sensors are mostly tethered. including tethered sensor would complicate the dynamics of the soft continuum robot and thus increase control difficulty
  + visual-based feedback is also mostly use for surgical tool tracking. visual-based controller of the surgical tools is developed making use of

the tracked position.

* what is the visual servoing definition in this paper?
  + control of a soft continuum robot, which mounted with camera at the tip, using only visual feedback
* what is the state-of-the art the visual-servoing for manipulation of endoscope?
  + control needs to compute the inverse mapping of the soft robot
    - mapping from the user input to the actuation pressure
    - usually redundancy is the problem of computing the inverse mapping
  + examples of model-based approach
    - e.g. PCC approach
  + model-based approach is difficult since it is difficult to obtain accurate analytical model of soft continuum robot
  + model-free approach of controlling
    - advantage of model-free approach
    - e.g. data-driven based approaches that approximate the inverse mapping by regression
    - local learning is one of the learning approach that can resolve the redundancy problem
      * have been successfully applied to learning inverse mapping for controlling redundant rigid-link robots
* contribution
  + visual-servoing of a soft continuum robot for laparoscopic surgery that can
    - enhance the tele-manipulation accuracy
    - automatically trace a target point specified in the endoscopic view

# Materials and methods

## Overall control architecture for tele-manipulation

* Explanation of the tele-manipulation in endoscopic navigation
  + Fig.1 : Schematic diagram of the overall control architecture
* Definition of the control problem
  + redundantly actuated soft robot
    - Fig. 2: sketch of the soft robot
  + we consider operational space control

## Model-free Kinematic control

### Inverse kinematics model of soft continuum robot

* general nonlinear function to describe the kinematic relation
  + quasi-static transition model [ref]
    - the robot is in stationary condition at time step with static chamber pressure $\bm{u}\_k$
    - the robot state is represented $\bm{x}\_k$
  + when the chamber pressure is changed by $\Delta\bm{u}\_k$, the state at the next time step is:
  + $\bm{x}\_{k+1} = f(\bm{x}\_k,\Delta\bm{u}\_k, \bm{\eta}\_k)$ or $\bm{x}\_{k+1} = f(\bm{x}\_k,\Delta\bm{u}\_k) + \bm{\eta}\_k$
  + where is unknown external disturbance
    - e.g. ???
  + The tip orientation $\bm{y}\_k$, and the corresponding metric in the image domain $\bm{z}$ are
    - $\bm{y}\_k = g\_{tip}(\bm{x}\_k)$
    - $\bm{z}\_k = g\_c(\bm{y}\_k) + \bm{\epsilon}\_k$
    - where is the measurement noise
* elaboration of this setting
  + relative to a base frame

### Learning the inverse model for operational space control

* online nonparametric method
* discuss the difference from related works regarding the learning/control methods

## Real-time image processing

* Fig.

# Results and discussion

# Conclusion