Integrated High -Dexterity Intraocular Micromanipulation

Paper Critique

Y.-J. Kim, S. Cheng, S. Kim, and K.Iagnemma, “A stiffness- adjustable hyperredundant manipulator using a variable neutral-line mechanism for minimally invasive surgery,” IEEE Transactions on Robotics, vol. 30, no. 2, pp. 382–395, 2014

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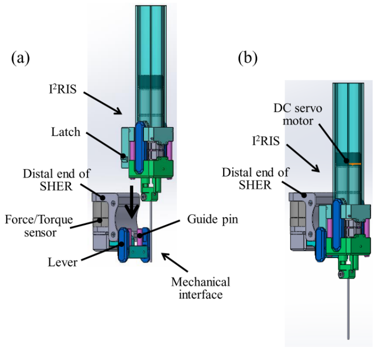
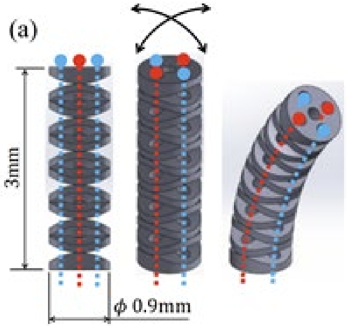
Project Overview



[2] Jinno et al., 2021



[2] Jinno et al., 2021

- Problem
  - Vitreoretinal surgery requires advanced surgical skills at or over the limit of surgeons' physiological capabilities due to space, force and motion limitations of the surgical tools
- Overall Goal
  - Provide surgeons a cooperatively controlled robotic system with snake - like distal end to help lower the difficulty level of procedure
- Project Goal
  - Integrate control of 2 DoF distal -end "snake like" manipulator I ^{2}RIS with 5 DoF Steady Hand Eye Robot so that user can control it to complete optimized trajectories

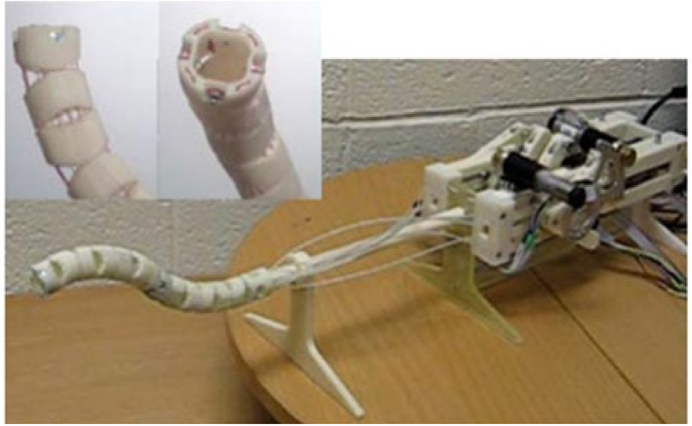
Paper Selection

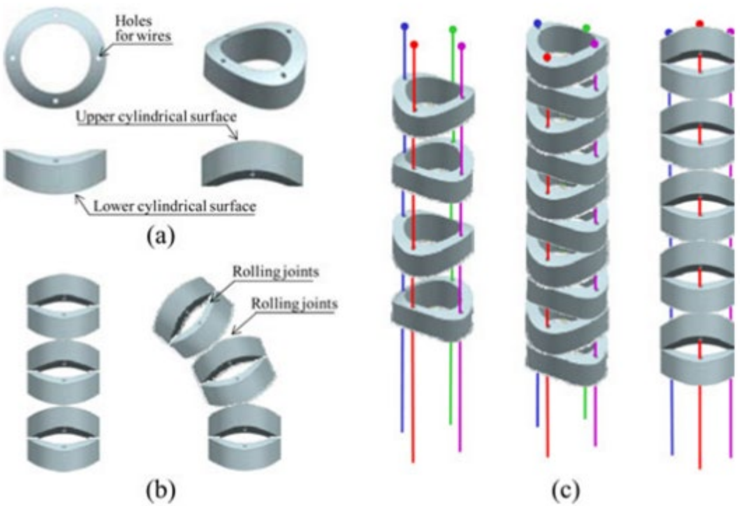
Y.-J. Kim, S. Cheng, S. Kim, and K.Iagnemma, “A stiffness-adjustable hyperredundant manipulator using a variable neutral-line mechanism for minimally invasive surgery,” IEEE Transactions on Robotics, vol. 30, no. 2, pp. 382–395, 2014

- Snake robot using neutral-line mechanism designed for minimally invasive surgery (MIS), which IRIS adopts
- Discussed the properties and working mechanism of the proposed snake robot
- The method of link-by-link analysis is highly relevant to the analysis of IRIS robot

Paper Summary

- A hyperredundant tubular manipulator with a variable neutral - line mechanism and adjustable stiffness
    - Design of mechanism
    - How to adjust stiffness
    - Design Implementation





[1] Kim et al., 2014

Key Takeaways

- Complete design and development of snake-like manipulator with 2 DOF
- Control input and output relationship
    - bending angle of the manipulator
    - movement of the wires
- Controllable stiffness of the manipulator
- Validation of the systems

Introduction and Background

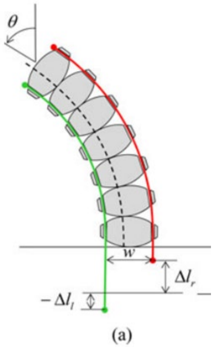
- Snake-like manipulators are receiving high attention due to interest in MIS
    - Low trauma, minimal scarring
    - Flexibility, safety, dexterity, potential for minimization
- Tunable stiffness for snake-like manipulators is very beneficial
    - High stiffness - high payload operation and exact positioning
    - Low stiffness - safe movement without harming internal organs

Paper: Basic Mechanics

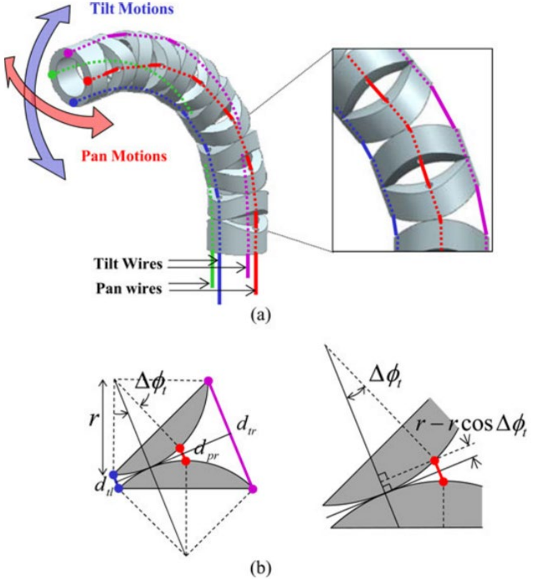
- Rolling joints, where the joint has arc - shape contact surfaces
- Two pairs of wires control 2 DOF
- Position of the neutral - line varies according to the pose of the proposed mechanism
- Fixed relationship between input wire length and output angle

$$\Delta l_{pl}(\theta_p, \theta_t) = 2nr\left(\cos\alpha - \cos(\alpha - \frac{\theta_p}{2n}) + 1 - \cos\frac{\theta_t}{2n}\right)$$

$$\Delta l_{pr}(\theta_p, \theta_t) = 2nr\left(\cos\alpha - \cos(\alpha + \frac{\theta_p}{2n}) + 1 - \cos\frac{\theta_t}{2n}\right)$$



[1] Kim et al., 2014, Fig 3

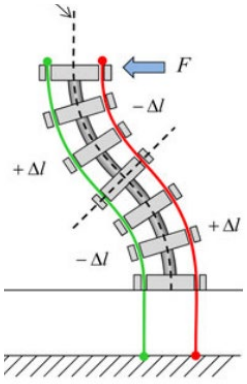


[1] Kim et al., 2014, Fig 6

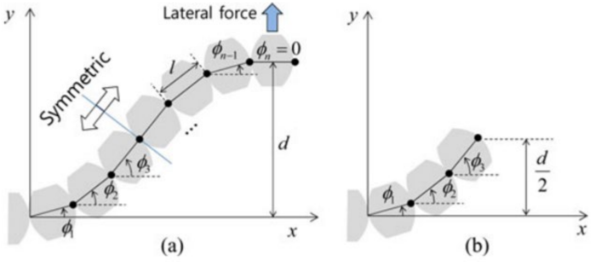
Paper: Deflection under External Force

- Approximated as revolute joint at small angle
- Simplified the problem to finding $\underset{\phi}{\arg\min}\,(\Delta l_l + \Delta l_r)$
- Fixed relationship between displacement and pose

$$\underbrace{\begin{bmatrix} 4 & -2 & & & & & 1 \\ -2 & 4 & -2 & & & & 1 \\ & -2 & 4 & -2 & & & 1 \\ & & \ddots & \ddots & \ddots & & \vdots \\ & & & -2 & 3 & -1 & 1 \\ & & & & -1 & 1 & 0 \\ 1 & 1 & 1 & \dots & 1 & 0 & 0 \end{bmatrix}}_{\equiv A} \begin{bmatrix} \phi_{m\times 1} \\ \lambda \end{bmatrix} = \underbrace{\begin{bmatrix} 0_{m\times 1} \\ d/2l \end{bmatrix}}_{\equiv c}$$



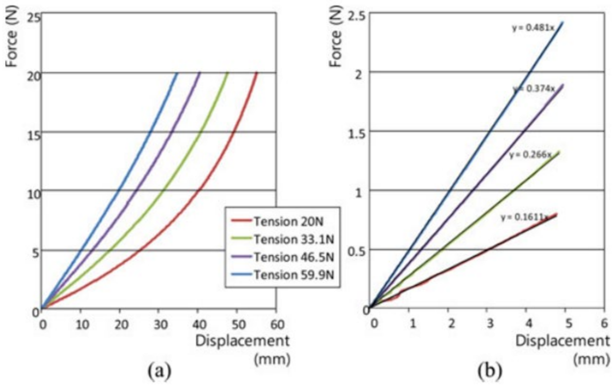
[1] Kim et al., 2014, Fig 2



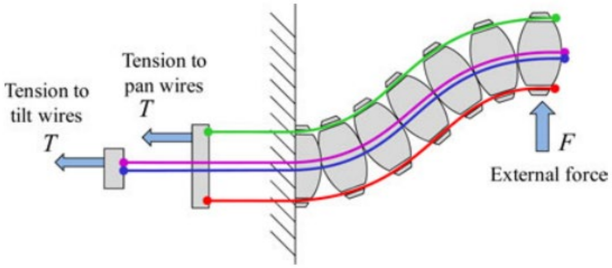
[1] Kim et al., 2014, Fig 7

Paper: Stiffness and Wire Tension

- Approximately linear relationship between tension and manipulator stiffness from calculation and simulation
- increasing joint number does not significantly affect the stiffness performance



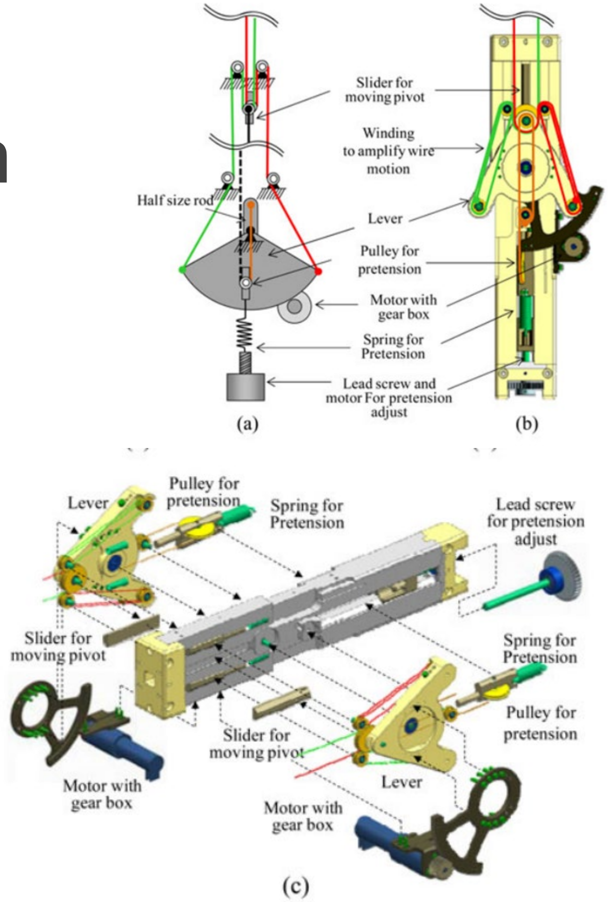
[1] Kim et al., 2014, Fig 8



[1] Kim et al., 2014, Fig 9

Paper: Design Implementation

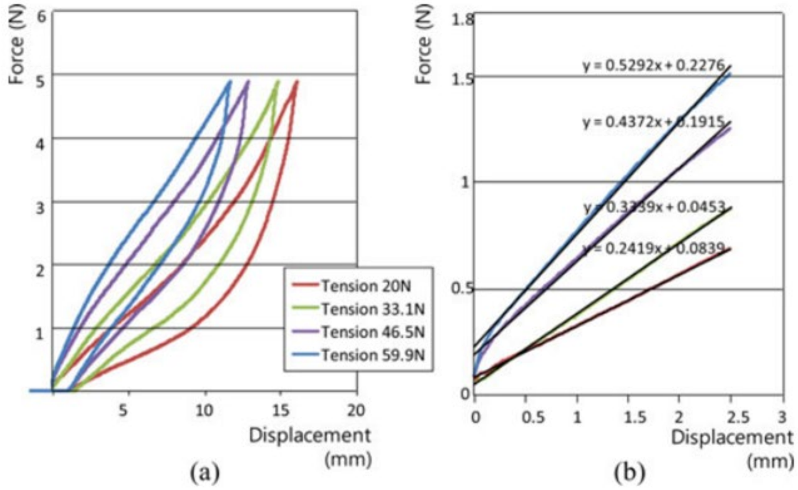
- Fan-shaped lever
  - a proportional relationship between actuator motion and manipulator motion.
- Lead screw and motor adjust pretension
- Winding to amplify wire motion



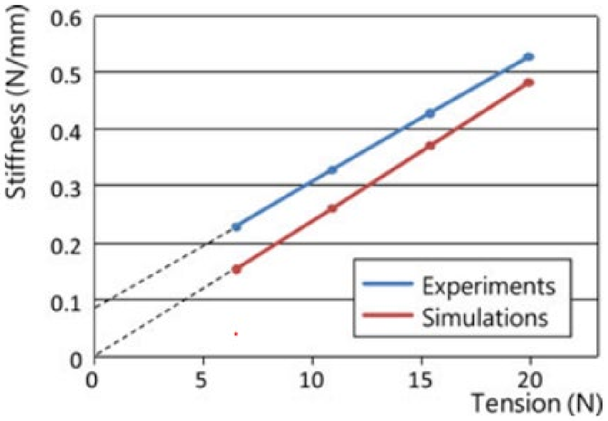
[1] Kim et al., 2014, Fig 13

Paper: Validation

- Maximum bending angle agrees with calculated value from geometry
- Hysteresis in real systems
- Difference between experiments and simulations due to frictions



[1] Kim et al., 2014, Fig 15



[1] Kim et al., 2014, Fig 16

Conclusion

- 2 DOF snake manipulator can be controlled by 2 pairs of wires
- Stiffness can be controlled by tension on the wires
- Small difference between simulated and real snake robot systems due to friction

Assessment - Good and Bad

- Good
  - Clearly explained geometric model
  - Clear link-by-link analysis of relationship between system parameters
  - Thorough discussion of the difference between experiments and simulation results
- Bad
  - Effect of stiffness on commanded motion
  - Lacks comparison between motion of the simulated system and real robot system

Assessment - Future Work

- Simplify the actuation mechanism
- Variation of the shape of the snake links
- Explore application the snake robot system
- Implement control algorithm with force sensing on the snake robot system

Assessment - Relevance

- Understanding of the I^2RIS robot geometry
- Input(motor rotation) - output(pitch/yaw) relationship model
- Methodology of link-by-link analysis
- Hysteresis indicated need for error estimation
- Validation method

Reference

[1] Y.-J. Kim, S. Cheng, S. Kim, and K.Iagnemma, “A stiffness-adjustable hyperredundant manipulator using a variable neutral -line mechanism for minimally invasive surgery,” IEEE Transactions on Robotics, vol. 30, no. 2, pp. 382–395, 2014

[2] Makoto Jinno, Gang Li, Niravkumar Patel, Iulian Iordachita, “An Integrated High -dexterity Cooperative Robotic Assistant for Intraocular Micromanipulation”, 2021., Kokushikan University

Questions?