Kinematic Synthesis in the Design of Continuum Robots

Yucheng Li

Advisors: Andrew Murray, Ph.D. and David Myszka Ph.D.

Department of Mechanical and Aerospace Engineering

University of Dayton

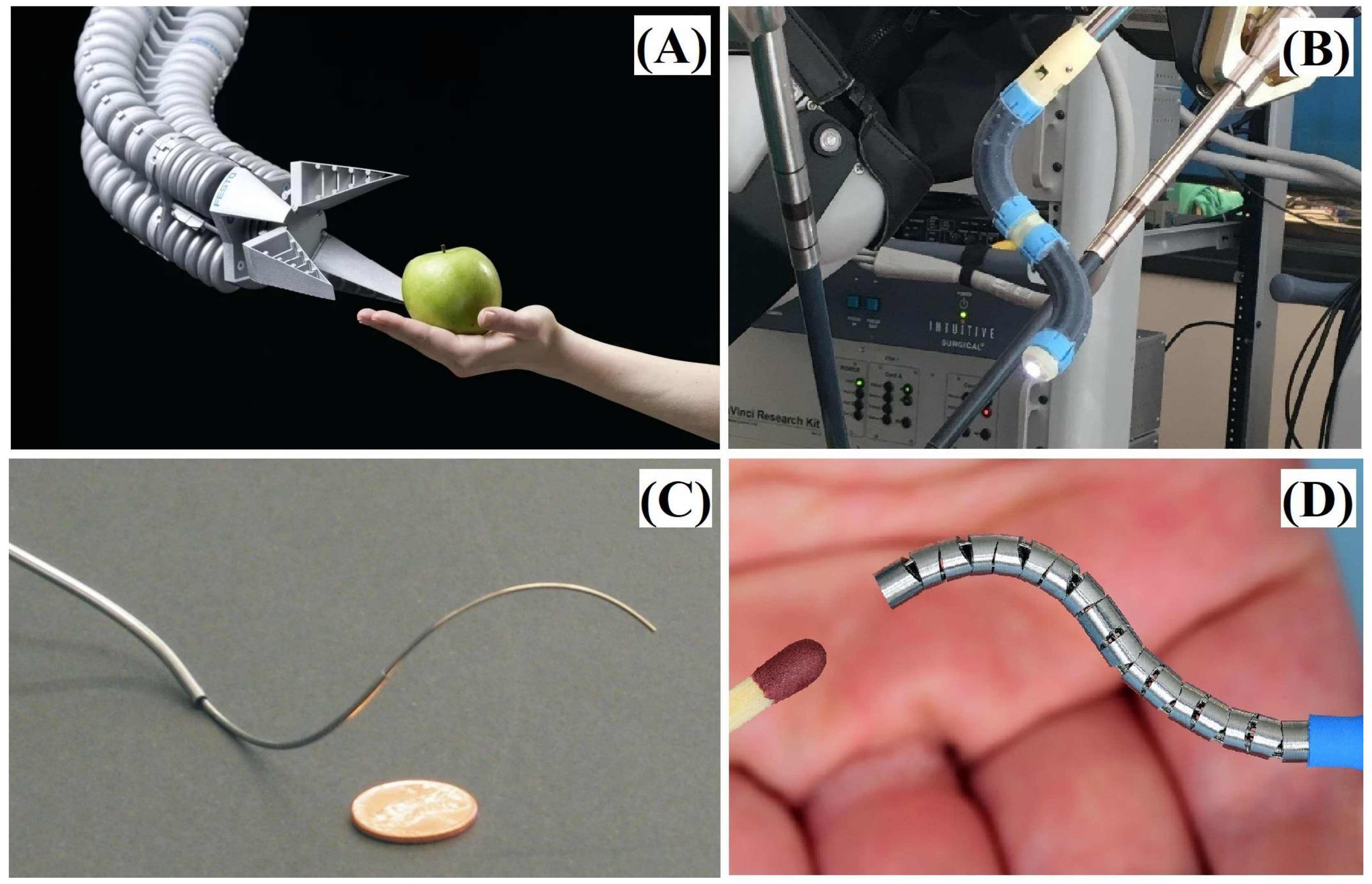
Objective: To advance the mathematical tools necessary for the modeling, kinematic design, and control of continuum robots.

Introduction

Compared to conventional factory-floor robots that consist of rigid links and joints, a continuum robot (CR) is built using flexible and elastic materials, enabling it to flexibly bend, twist, and stretch similar to biological organisms.

Applications

- Medical: minimally invasive surgeries
- Inspection: hard-to-reach areas
- Manufacturing: complex assembly/manipulation
- Search & Rescue: disaster areas/buildings
- Aerospace: space exploration/maintenance.

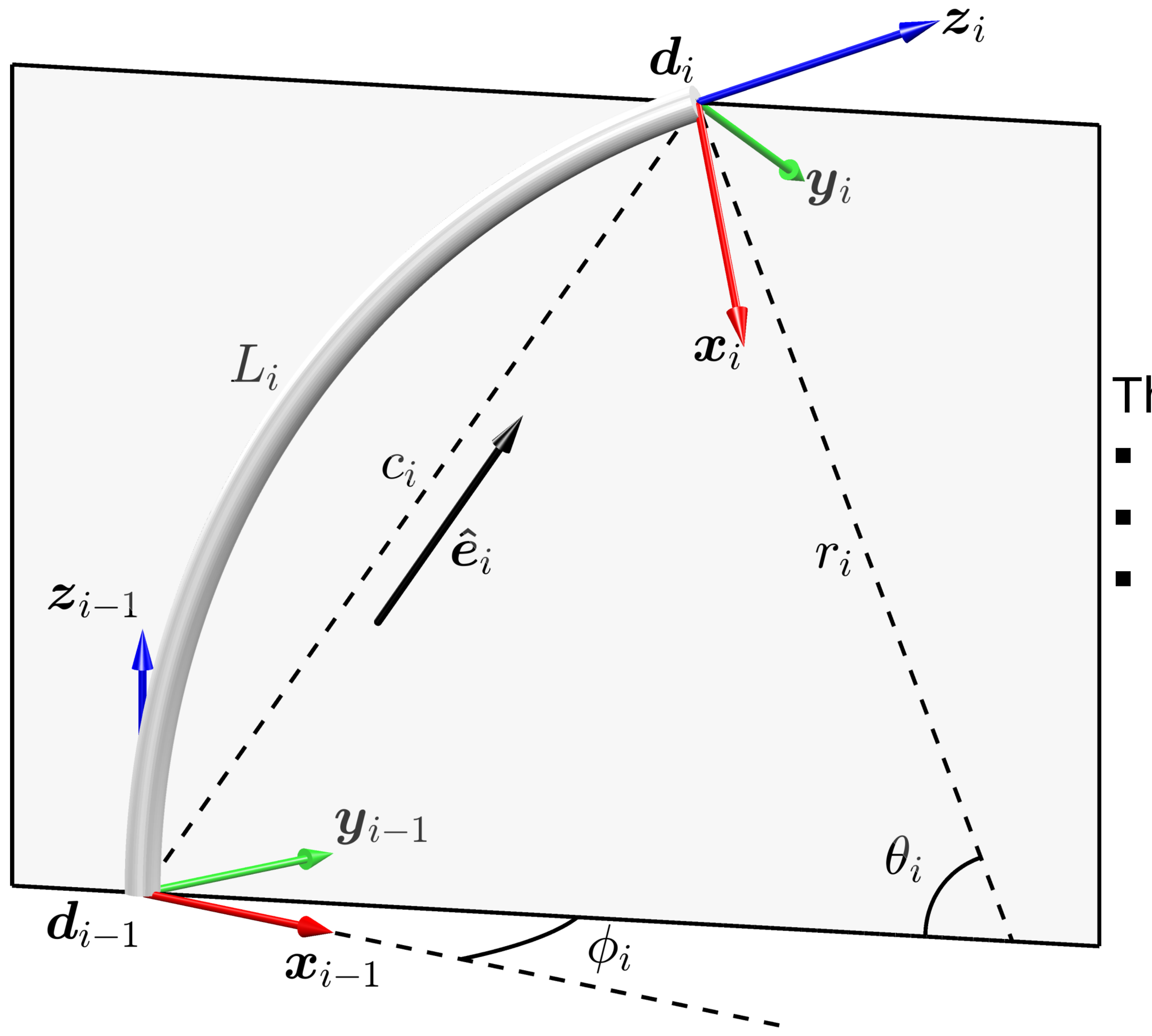


(A) Festo's Bionic Handling Assistant is combined from several pneumatically actuated bellows [1]. (B) An endoscope is constructed using a soft manipulator made of silicone that consists of two modules and is referred to as STIFF-FLOP [2]. (C) A prototype active cannula made of precurved superelastic Nitinol tubes [3]. (D) A multi-steerable catheter developed by the BITE-group at TU Delft for complex procedures inside the heart [4].

Dexterity Analysis

Num of Seg	DoF Robot	DoF at EE	Redundancy
1	3	3	0
2	6	5	1
3	9	6	3
4	12	6	6
⋮	⋮	⋮	⋮
m	3m	6	3m-6

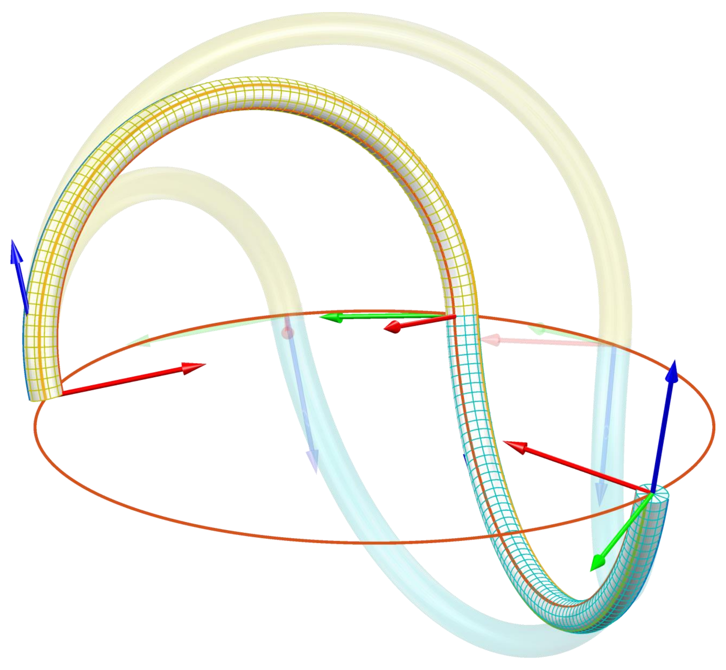
One-Segment CR with Notation



Three Parameters:

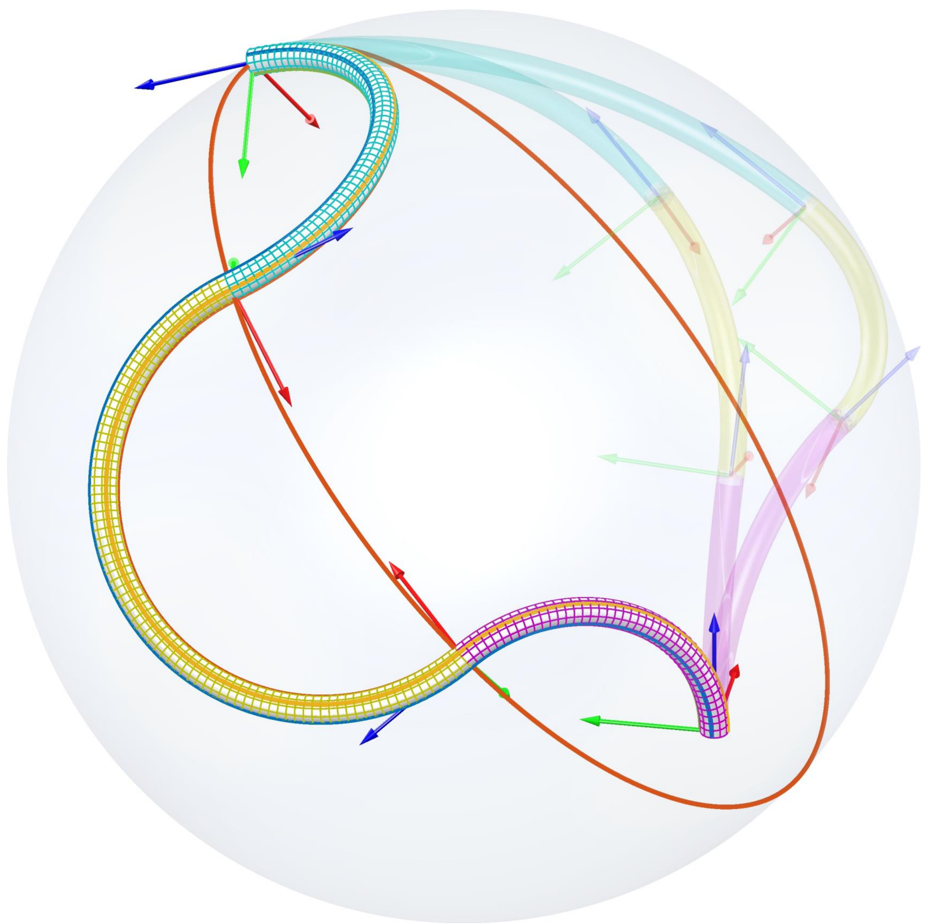
- segment length L_i
- bending angle θ_i
- angle of bending plane φ_i

Two-Segment Kinematic Redundancy



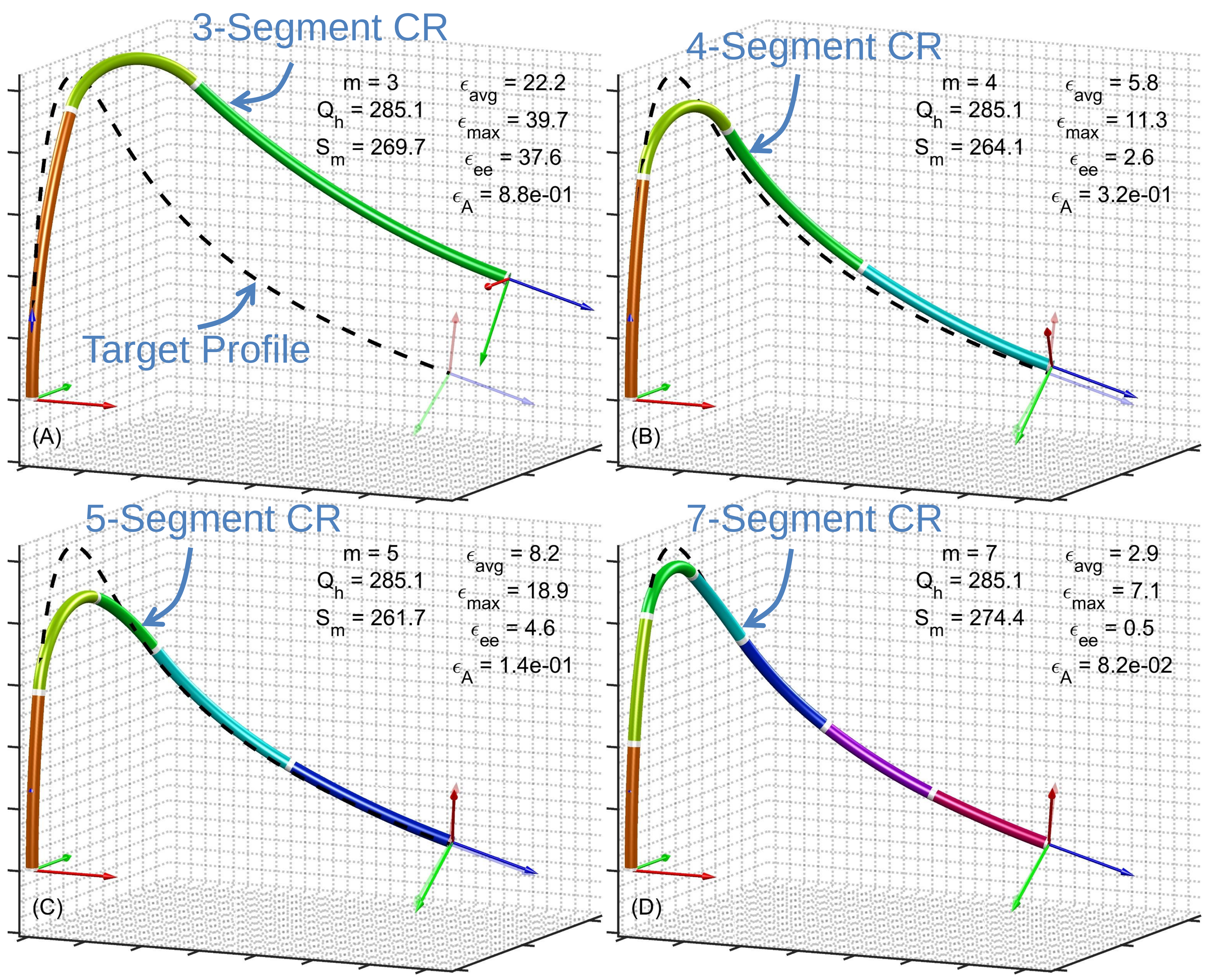
The IK problem of a two-segment CR has 1-DoF redundancy, and its three junctions lie on the same circle. Given the positions and orientations of both ends, the middle junction can be placed anywhere on the circle.

Three-Segment Kinematic Redundancy

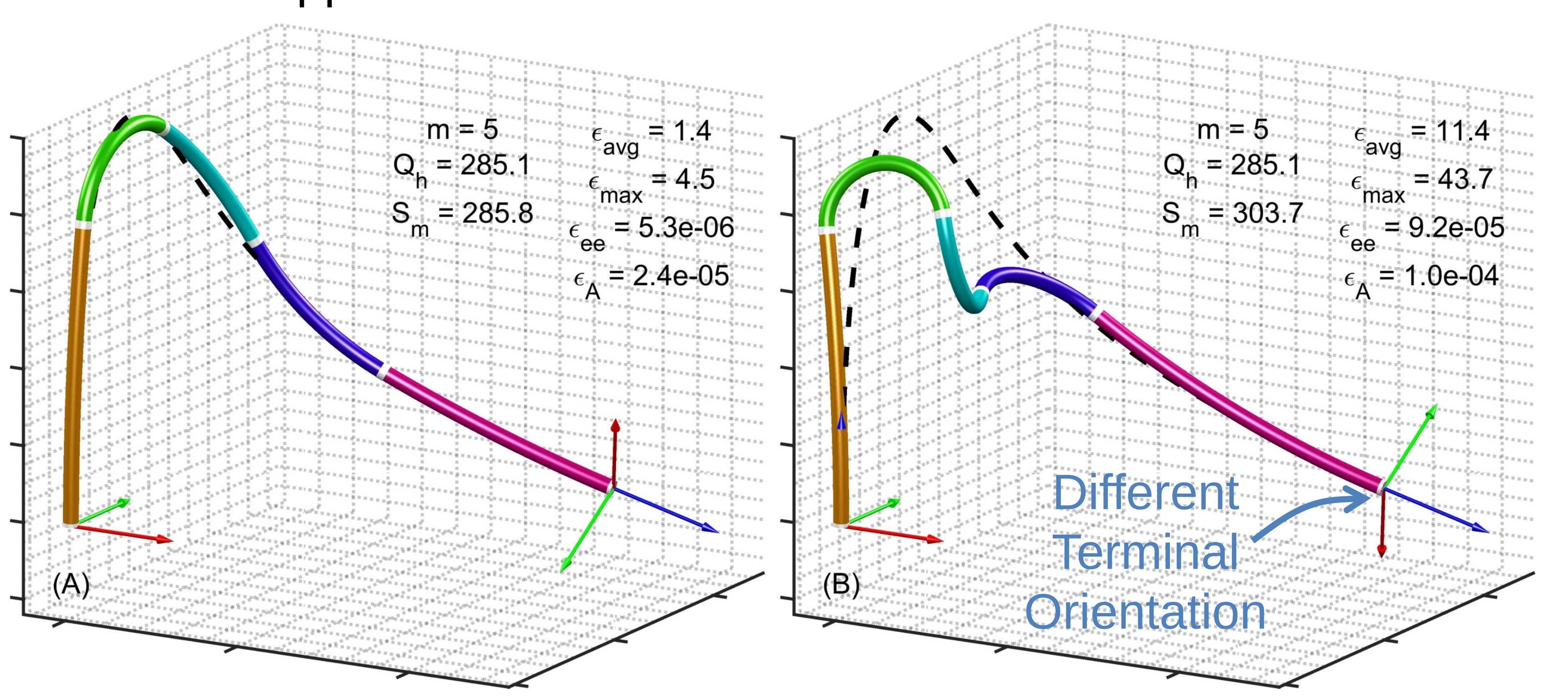


The IK problem of a three-segment CR has 3-DoF redundancy, with its four junctions on the same sphere determined by the endpoints' positions and orientations. One middle junction is freely positioned on the sphere, while the other is fixed to the corresponding junction circle.

Rapid Approximation Method



The rapid approximation method is to generate a CR with a given number of segments that closely approximates a spatial curve. An increase in the number of segments in the backbone is observed to reduce the approximation error.



An optimization process yields a five-segment CR with different given terminal orientations to approximate the same target profile.

Acknowledgements

- This work has been supported in part by the University of Dayton Office for Graduate Academic Affairs through the Graduate Student Summer Fellowship Program.
- University of Dayton Research Institute provides support for the manufacturing processes utilized in the verification of the technology described in this research.

References

[1]. Falkenhahn, V., Hildebrandt, A., Neumann, R., & Sawodny, O. (2016). Dynamic control of the bionic handling assistant. *IEEE/ASME Transactions on Mechatronics*, *22*(1), 6-17.

[2]. Ranzani, T., Gerboni, G., Cianchetti, M., & Menciassi, A. (2015). A bioinspired soft manipulator for minimally invasive surgery. *Bioinspiration & biomimetics*, *10*(3), 035008.

[3]. Webster, R. J., Okamura, A. M., & Cowan, N. J. (2006, October). Toward active cannulas: Miniature snake-like surgical robots. In *2006 IEEE/RSJ international conference on intelligent robots and systems* (pp. 2857-2863). IEEE.

[4]. Ali, A., Sakes, A., Arkenbout, E. A., Henselmans, P., van Starkenburg, R., Szili-Torok, T., & Breedveld, P. (2019). Catheter steering in interventional cardiology: Mechanical analysis and novel solution. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, *233*(12), 1207-1218.