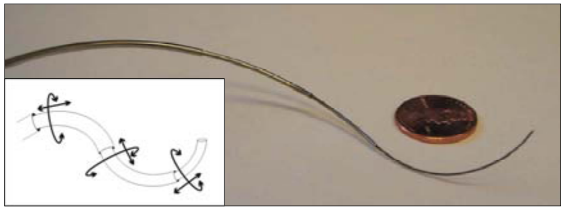
Toward a General Active Cannula Model

D. Caleb Rucker, Noah J. Cowan, Gregory S. Chirikjian, Robert J. Webster III
Medical and **E**lectromechanical **D**esign **Lab**, Vanderbilt University

VANDERBILT UNIVERSITY

Introduction

- A needle-scale continuum robot
- Uses elastic interaction to "steer" in free space or embedded in tissue



Motivation

- Improve model predictive accuracy: account for bending and torsion throughout cannula
- Enable patient-specific active cannulas with general (non-circular) precurvature functions

Modeling Approach

- Coordinate free formulation
- Based on minimization of energy functional

$$E = \frac{1}{2}\sum_{i=1}^{n}\int_0^L [\omega_i(s) - \omega_i^*(s)]^T K_i(s)[\omega_i(s) - \omega_i^*(s)]ds$$

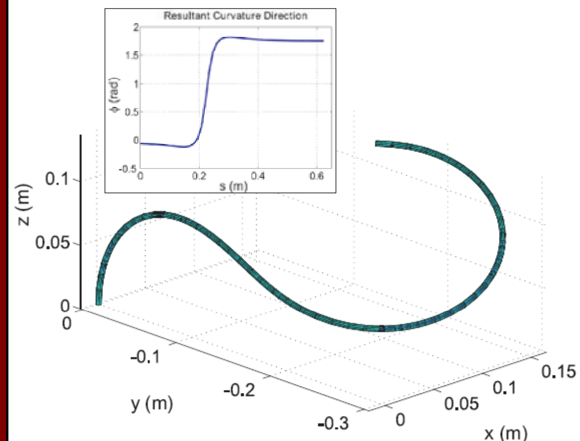
- Can account for bending and torsion generally, variable stiffnesses, and precurvatures that are functions of tube arc length
- Can be converted into a set of DEs via Euler-Lagrange, and Euler-Poincare methods.
- Previous models are special cases of this general framework
- In the two-tube case, an analytical solution is possible:

$$\frac{G_1J_1G_2J_2}{G_1J_1 + G_2J_2}\ddot{\theta} - \kappa_1\kappa_2\frac{E_1I_1E_2I_2}{E_1I_1 + E_2I_2}\sin\theta = 0$$

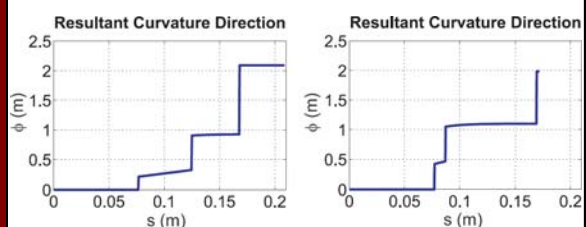
- Analogous to nonlinear inverted pendulum ODE

Simulation Results

Simulation of two, long, circularly curved tubes. Inner tube rotated 350° with respect to outer



- With torsion in curved sections, cannula equilibrium shape is non-circular
- Also true for "multi-link" active cannulas



- For a piecewise circular cannula, the above plots would be flat, stepped, functions
- Slopes are not severe, demonstrating why, for short arc lengths, initial models without general torsion predicted arc parameters reasonably well
- However, even "small" arc parameter errors can be significant for tip pose (see next column)

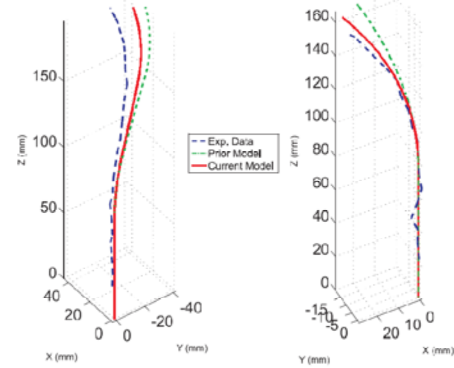
Citations/Funding

[1] D. Caleb Rucker and Robert J. Webster III, "Mechanics-Based Modeling of Bending and Torsion in Active Cannulas," *IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics*, 2008. (In press)

[2] Robert J. Webster III, D. Caleb Rucker, Noah J. Cowan, Gregory S. Chirikjian, "Equilibrium Conformations of Concentric-Tube Continuum Robots" *IEEE International Journal of Robotics Research.* (In preparation)

Supported by NSF CBET # 0651803, and Vanderbilt University

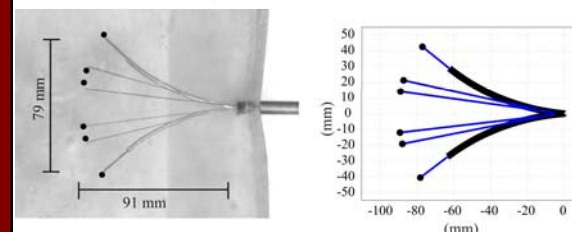
Experimental Results & Comparison to Prior Models



- New model reduces error 72% error over the bending only model and 35% over the transmissional torsion model
- Average tip error is 6.5mm without fitting

Tissue-Embedded Experiments

- Liver ablation simulation shows workspace suitable for a large tumor



- 2.4 mm curved tube deploys straight ablator in fairly stiff rubber phantom (stiffer than tissue)
- Tube is sufficiently stiff such that a free-space model can be used for shape prediction (tissue causes only a 1.6% change in curvature).

Canine prostate ablated with acoustic ablation probe, suitable for delivery via active cannula. Image courtesy of Acoustic Medsystems.

Mechanical Engineering Department – Vanderbilt University – Nashville, Tennessee
daniel.c.rucker@vanderbilt.edu
http://research.vuse.vanderbilt.edu/MEDLab/index.htm