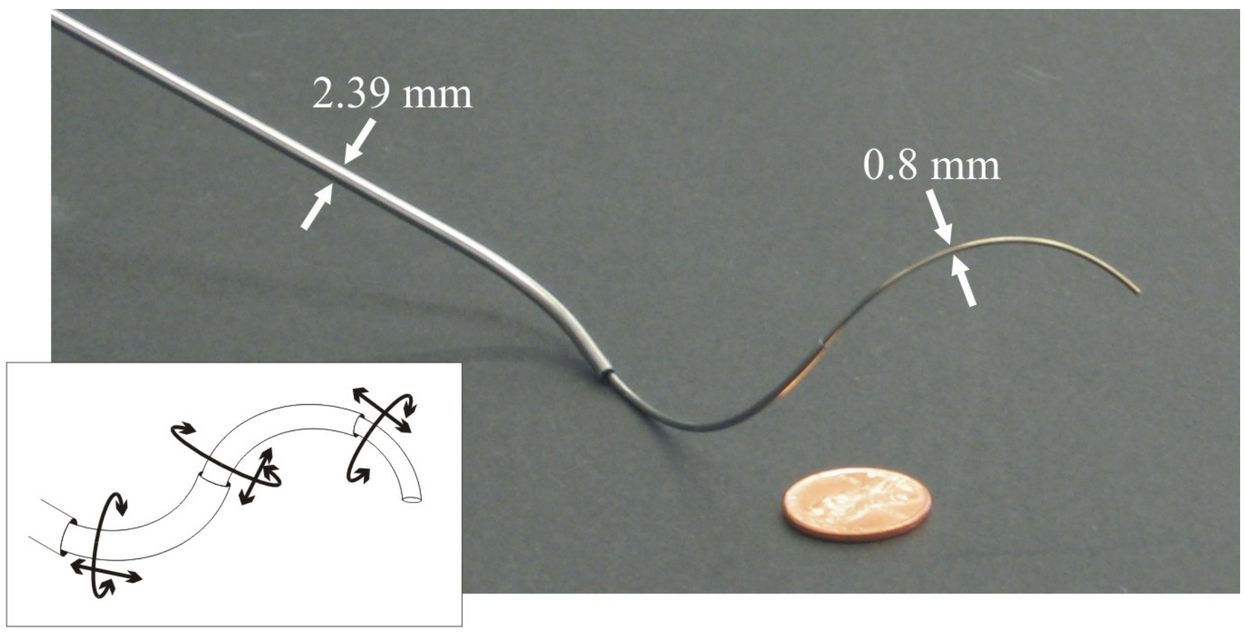
Image Guidance of Active Cannulas

Introduction: Active Cannulas

• Active cannulas are miniature, **highly compliant**, dexterous robots ideal for navigating tortuous anatomy
• Made from concentric pre-curved flexible (Nitinol) tubes
• Actuated from the base via tube rotation & insertion
• Small diameter design; inherent miniaturization
• Tunable stiffness through tube selection; compliance enhances safety
• Mechanically simple; actuated robotically or manually

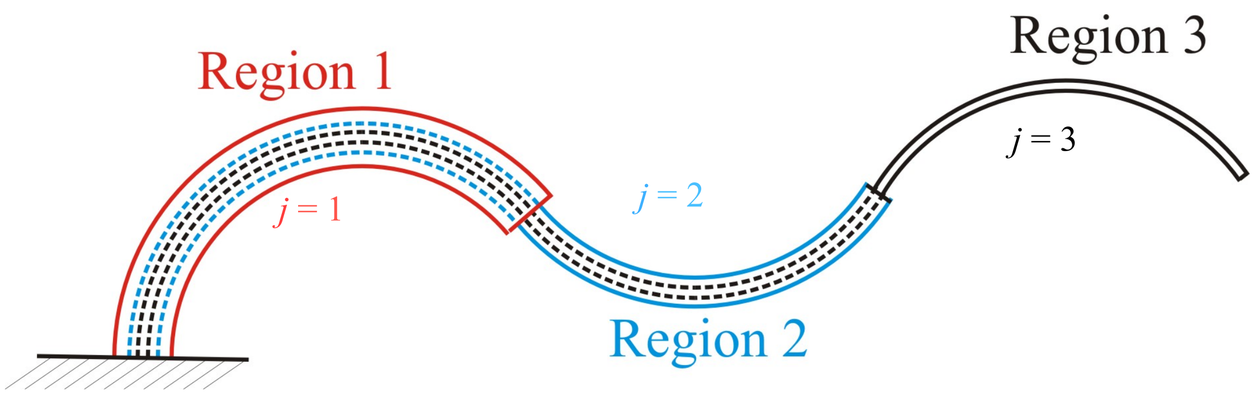


The Problem

• Active cannula compliance renders the **final pose difficult to predict** from forward kinematics alone.

The Solution: Image Guidance

Kinematics of Active Cannula



• Cannula shape can be expressed in terms of piecewise planar arcs. Tip pose is the result of all the arcs:

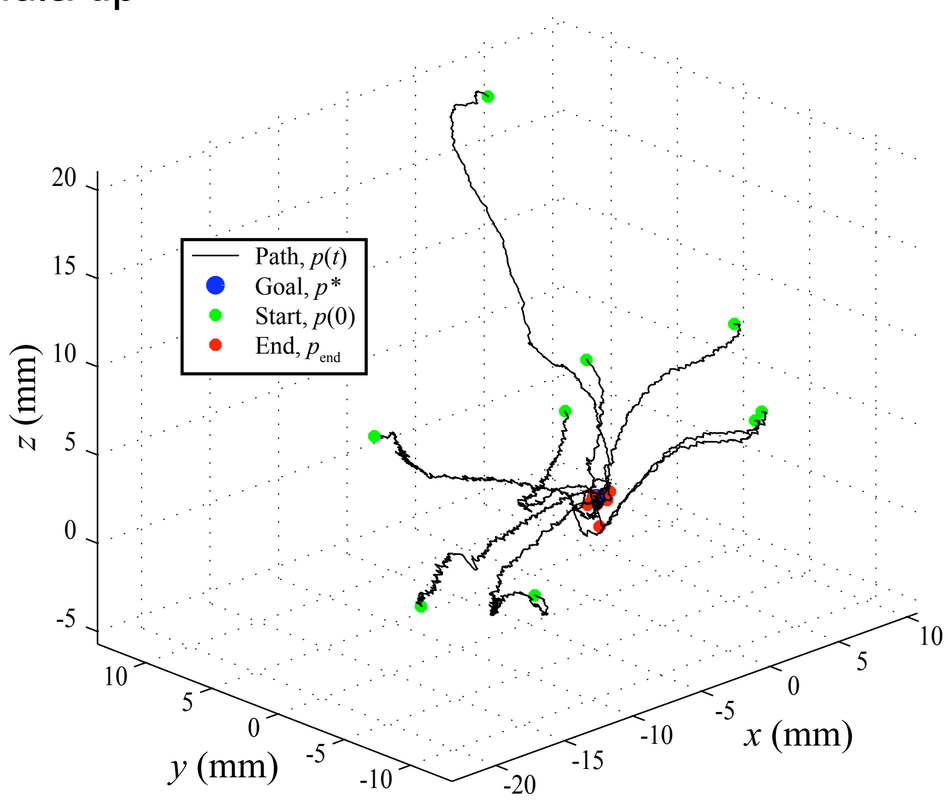
$$g = g_0 g_1 \cdots g_m, \quad g_j = e^{\widehat{\boldsymbol{e}}_6 \Delta\phi_j} e^{(\widehat{\boldsymbol{e}}_3 + \widehat{\boldsymbol{e}}_4 \kappa_j)\ell_j}, \quad j = 1, 2, \ldots, m,$$

•Cannula shape is determined through minimization of stored elastic energy.
• Jacobian relates velocities of the cannula tip (or any other point on the cannula) to joint velocities:

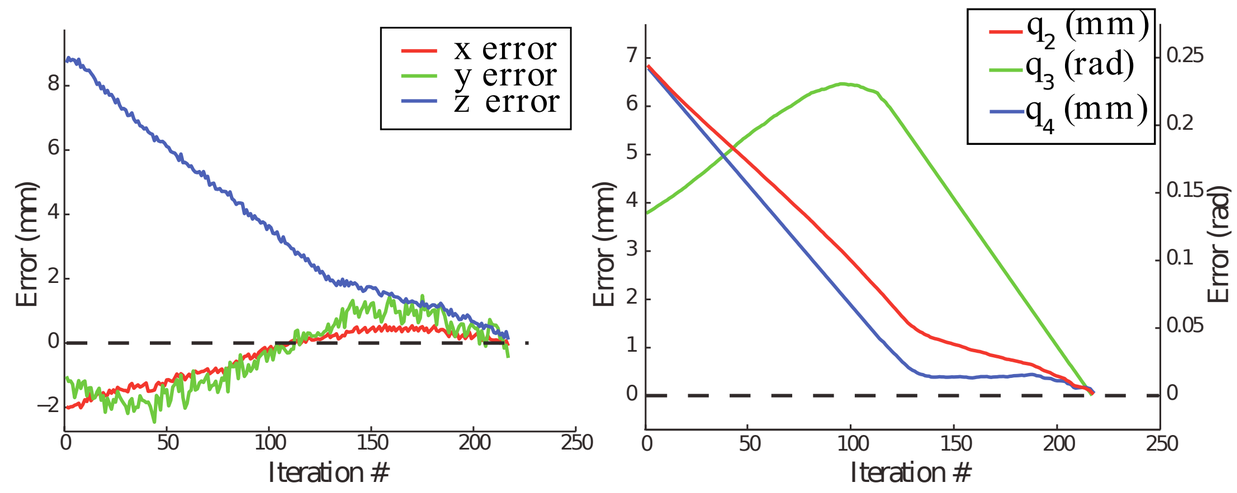
$$V_{st}^s = \left(\dot{g} g^{-1}\right)^{\vee} = J_{st}^s \dot{\boldsymbol{q}}$$

Image Guidance of Active Cannula

• Position-based visual servo controller guides the cannula tip



Experimental trials - Initial displacement: 8.80-21.76 mm
Final error: 1.543 mm maximum, 0.674 mm average



(Left) The convergence in each axis of the 3D position of the cannula tip for a single trial. (Right) The error between the joint variables and their values at the goal position.

Impact and Future Work

Impact

• Image-guidance will facilitate tele-operated and fully automatic control strategies.

Future Work

• Validate for a many tubes; many degrees of freedom.
• Combine the open-space dexterity of active cannula with the in-tissue dexterity of steerable needles.
• Develop algorithms for medical imaging modalities.

PEOPLE INVOLVED

- Graduate students: John Swensen (JHU)
- Undergraduates: Joe Romano (JHU; now @ Penn)
- Engineering Faculty: Noah Cowan (JHU) and Robert Webster (Vanderbilt)

PUBLICATIONS

1 R. Webster III, J. Romano, and N. Cowan. IEEE Trans. Robot. 2009.

2 R. Webster III, J. Swensen, J. Romano, and N. Cowan. ISER 2008.

SUPPORTED BY:

- NIH Grant R01-EB006435
- NSF Grant CBET-0651803
- CISST ERC (NSF Grant EEC-9731748)