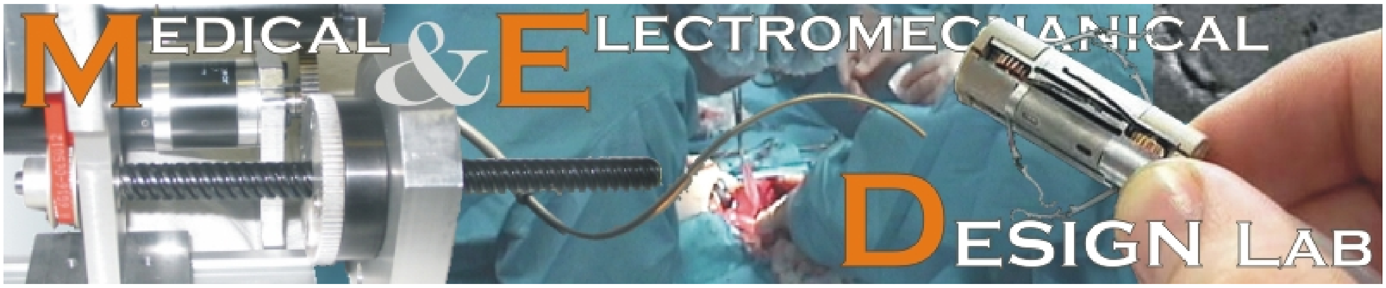

Aiming Surgical Lasers With an Active Cannula

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An active cannula is a surgical device capable of dynamically changing its curved shape in response to rotation and translation of the several precurved, concentric, superelastic (Nitinol) tubes from which it is made [1] (Figure 1). As the tubes move with respect to one another in response to input motion at their bases (outside the patient), they elastically interact, causing one another to bend. This bending can be harnessed to direct the cannula through winding trajectories within the human body. An active cannula robot has the potential to perform a wide range of surgical tasks, and it is especially well suited for guiding and aiming an optical fiber (e.g. BeamPath from OmniGuide, Inc.) for laser ablation as depicted in the figure to the right. Controlling the trajectory of the laser requires control of the shape of the active cannula, and in particular the position of its tip. Prior work has shown that beam mechanics can be used to describe the shape of the cannula given the translations and axial angles of each tube [1]. Here, in order to aim the laser, we invert this relationship ("inverse kinematics"), solving for the translations and axial angles of each tube, given a desired position of the cannula tip.

Figure 1. Prototype active cannula for aiming a surgical laser fiber.

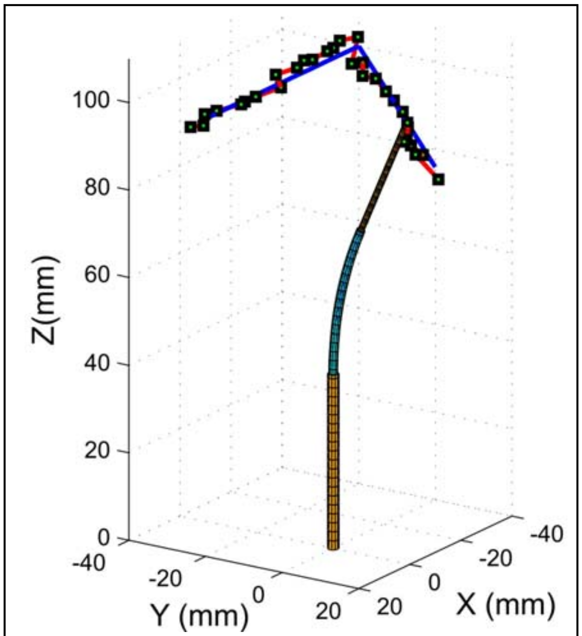

Figure 2. Experimental results when aiming a simulated laser with the active cannula. The solid lines that intersect at the top of the figure are a desired trajectory. Tube translations and rotations needed to place the laser at points along it were determined via inverse kinematics and applied at tube bases. Tip position (squares) were then measured via an optical tracking.

Our experimental prototype cannula (Figure 1) consists of three tubes. The outermost tube is straight and rigid (stainless steel). The middle tube is flexible (Nitinol) and precurved into a circular arc, the shape to which it returns as it is extended. The innermost tube is straight and flexible – we use it to represent the straight trajectory of the laser to the tissue surface. We performed an experiment (Figure 2) to assess the validity of the inverse kinematic model and the accuracy of our prototype. The location of the tip was measured with an Sx60 Optical Tracker (Claron Technology, Inc.). The green squares show the actual tip locations achieved, representing the path of the laser beam on the tissue surface. Mean tip error was 3.1mm (max 5.5mm). This experiment demonstrates the usefulness of the model, which can assist in the design of custom cannulas for guiding lasers in specific surgical procedures.

[1] Webster, R. J. III, Romano, J. M., and Cowan, N. J., 2009, "Mechanics of Precurved-Tube Continuum Robots," IEEE Transactions on Robotics, 25(1), 67-78, 2009

Aiming a Surgical Laser with an Active Cannula

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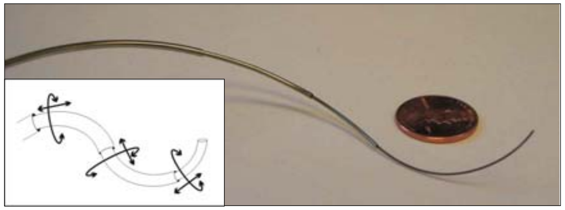
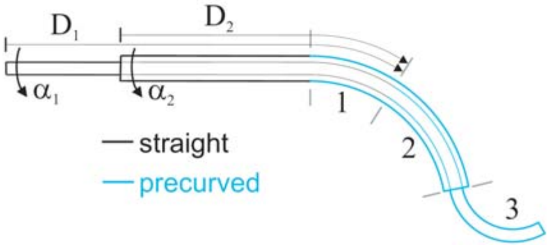
The Active Cannula

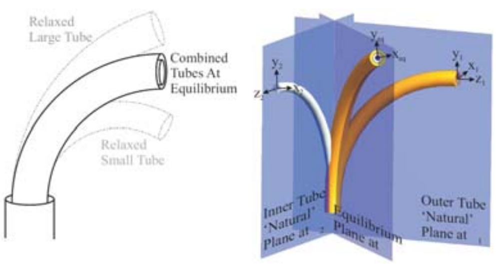
- A needle-scale, tentacle-like, continuum robot
- Uses superelastic precurved concentric tubes to "steer" in free space or embedded in tissue



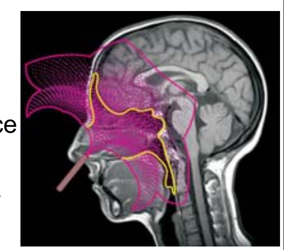
Remote Actuation



- Component tubes are rotated and translated at the base (proximal end) of the robot.
- Beam mechanics describes device shape [1,2].



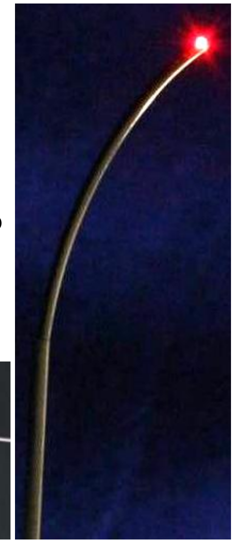
- Precurved sections of tubes elastically bend each other into an equilibrium shape.
- Can assume a wide range of curved shapes and follow winding paths
- Exhibits large workspace
- Shapes/properties of tube can be designed for specific applications



Medical Applications

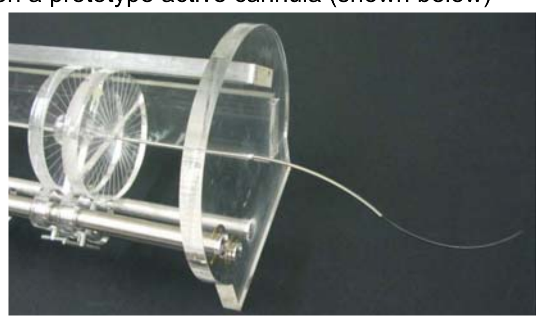
Central channel useful for:

- Biopsy collection
- Drug delivery
- Guiding fiber optics for imaging or ablation
- Actuating a gripper at the tip
- Delivering any other diagnostic or therapeutic agent a needle can deliver



Kinematics Algorithm/Experiments

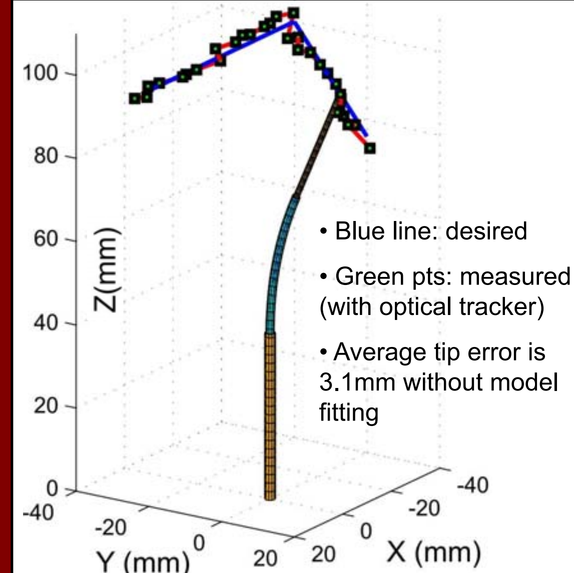
- **Problem:** What base rotations and translations are necessary to achieve a desired tip position and orientation?
- **Solution:** Accurately model the active cannula using beam mechanics, and invert the mapping
- **Experimental Validation:** Compute via points along a desired tip trajectory and implement them on a prototype active cannula (shown below)



Funding

NSF CBET # 0651803, NIH #1R44CA134169-01A1, and Vanderbilt University

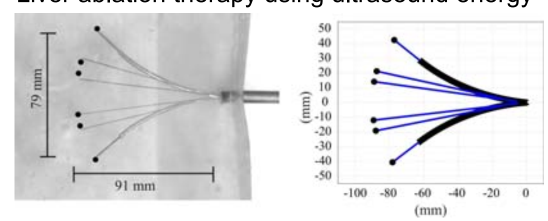
Experimental Results



- Blue line: desired
- Green pts: measured (with optical tracker)
- Average tip error is 3.1mm without model fitting

Tissue-Embedded Applications

- Liver ablation therapy using ultrasound energy



- Active cannula deploys ablator in phantom tissue
- Free-space model can be used for shape prediction (tissue causes only a 1.6% change in curvature).

Acoustically ablated canine prostate. We are currently integrating this ablator with an active cannula. Image courtesy of Acoustic Medsystems, Inc.

References

[1] RJ Webster III, JM Romano, and NJ Cowan, "Mechanics of Precurved-Tube Continuum Robots," IEEE Transactions on Robotics, 25(1), 67-78, 2009.
[2] DC Rucker and RJ Webster III, "Mechanics of Bending, Torsion, and Variable Precurvature in Multi-Tube Active Cannulas" IEEE ICRA 2009.