



Motion Planning for Tentacle-like Medical Robots

Department of Computer Science

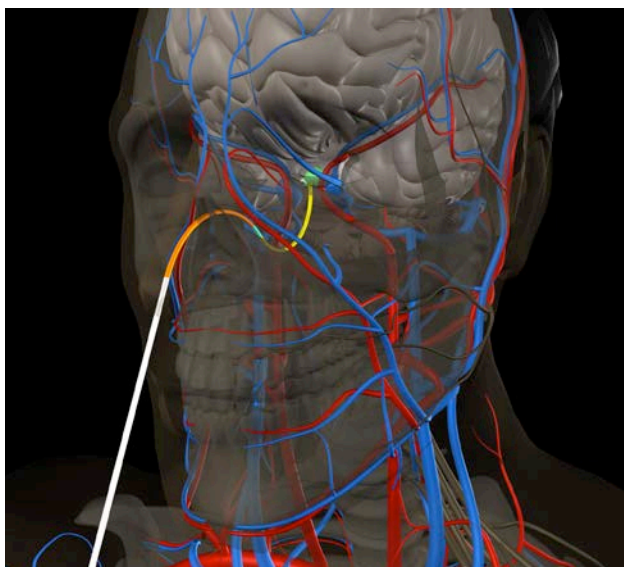
University of North Carolina at Chapel Hill

March 2012

The Challenge

Concentric tube robots are continuously flexible tentacle-like robots that can trace curved paths through open air or soft tissues. They can be controlled to reach distant targets in constrained spaces, making them well suited for minimally invasive surgery. Provided that appropriate motion planning and control algorithms can be developed, concentric tube robots have the potential to enable new safe, dexterous, minimally invasive access to the lung via the throat and to the brain at the skull base via the nasal cavity. This could lead to more accurate diagnoses and effective treatments for lung and brain cancers.

Concentric tube robots are composed of thin, nested tubes that rotate and telescope with respect to one another. Each tube is pre-curved, shaped for example as a straight transmission segment followed by a segment with constant curvature. Each tube, typically composed of nitinol, can be controlled independently by two degrees of freedom: it can be (1) rotated axially, and (2) pushed/retracted through the containing tube. These degrees of freedom could be robotically actuated or directly controlled by a human operator. When rotating or telescopically extending any of the component tubes of the robot, the device's entire shape changes due to interactions among the pre-curvatures of the individual tubes. Paired with effective motion planning algorithms, concentric tube robots have the potential to enable new minimally invasive procedures.



Virtual simulation of a concentric tube robot executing a motion plan for neurosurgery at the skull base. The robot is inserted through the nostril and guided toward the pituitary gland (highlighted in green) in the skull base while avoiding cartilage, bone, blood vessels, and healthy brain tissue. The component tubes of the robot are colored white, orange, cyan, and yellow.

Highlights

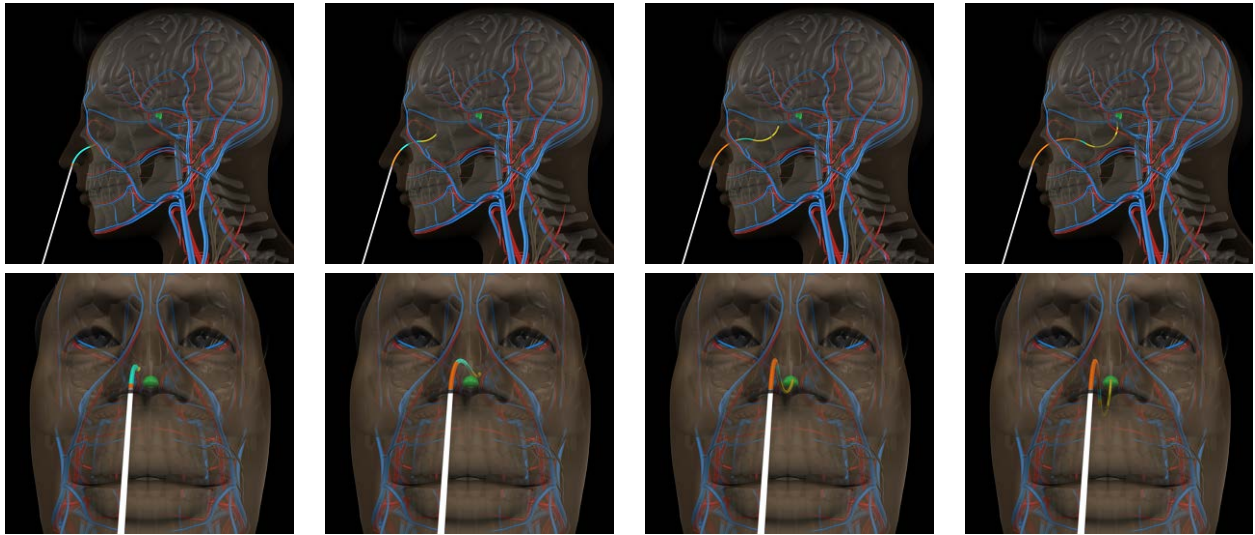
- **Concentric tube robots are tentacle-like robots that can be controlled to trace curved paths through open air or soft tissues.**
- **Paired with effective motion planning algorithms, concentric tube robots have the potential to enable new minimally invasive procedures.**
- **We are developing new motion planners to maneuver concentric tube robots to clinical targets while minimizing the probability of colliding with anatomical obstacles.**
- **We are investigating applications to neurosurgery and cardiothoracic surgery.**

The Approach

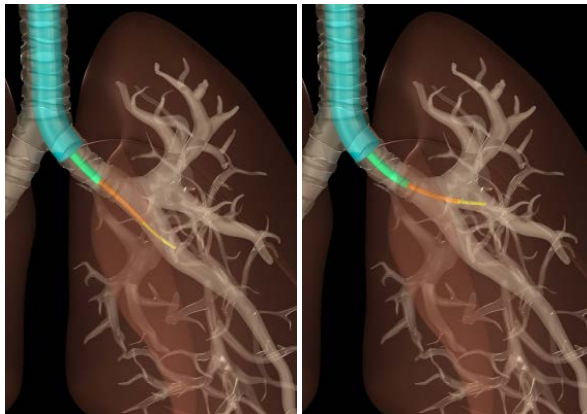
We are developing new motion planning algorithms to maneuver tentacle-like concentric tube robots to clinical targets while minimizing the probability of colliding with anatomical obstacles. We consider obstacles that should not be contacted, penetrated, or damaged by the cannula, such as nerves, blood vessels, bones, critical brain structures, or other delicate tissues defined by medical doctors. Our planning algorithm is intended for use in image-guided procedures where the target and obstacles can be segmented from pre-procedure images such as Magnetic Resonance Imaging (MRI), Computed Tomography (CT), or Ultrasound.

The power and flexibility of concentric tube robots comes at the cost of modeling and planning complexity. The shape of a concentric tube robot is a function of the control inputs, which are the rotation and extension of each of the component tubes. The shape is governed by the interplay of beam mechanics and torsional effects among the tubes. There is no known closed-form solution to the kinematics of concentric tube robots. A further complication in real world scenarios is uncertainty in actuation and in the kinematic model of the robot which can result in deviations from the predicted motion. This motion uncertainty must be considered in order to maximize the probability of successfully performing a task.

We are developing a motion planning algorithm that computes the control inputs that guide the robot to a target point while minimizing the probability of collision with obstacles in the environment. Our planner uses a highly accurate kinematic model of concentric tube robots. The



A step-by-step illustration of our simulation of the minimally invasive skull base procedure that accesses the brain via the nasal cavity. The concentric tube robot is inserted based on a motion plan that reaches a clinical target at the skull base while avoiding obstacles including cartilage, bone, blood vessels, and healthy brain tissue. The same procedure is shown from two perspectives.



Simulation of a concentric tube robot reaching two pre-specified clinical targets in the bronchial tubes of a human lung.

planner also considers the effect of uncertainty in the estimated shape of the concentric tube robot. We integrate these models with a new sampling-based approach called the Rapidly Exploring Roadmap to guarantee finding optimal plans as computation time is allowed to increase. Our planner computes plans that minimize the estimated probability of colliding with sensitive structures.

This project is part of a collaboration with Mechanical Engineering at Vanderbilt University and clinicians at both UNC-Chapel Hill and Vanderbilt. We have demonstrated our motion planner in simulation using a variety of evaluation scenarios including an anatomy-based neurosurgery case that requires maneuvering to a difficult-to-reach brain tumor at the skull base.

Current Project Members

Ron Alterovitz (Principal Investigator), Assistant Professor

Luis G. Torres, Graduate Research Assistant

Research Sponsors

National Science Foundation (NSF) under grant #IIS-0905344 and the National Institutes of Health (NIH) under award R21EB011628.

Selected Publications

Luis G. Torres and Ron Alterovitz, “**Motion Planning for Concentric Tube Robots Using Mechanics-based Models**,” in *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Sept. 2011, pp. 5153-5159.

Ron Alterovitz, Sachin Patil, and Anna Derbakova, “**Rapidly-Exploring Roadmaps: Weighing Exploration vs. Refinement in Optimal Motion Planning**,” in *Proc. IEEE International Conference on Robotics and Automation (ICRA)*, May 2011, pp. 3706-3712.

Lisa A. Lyons, Robert J. Webster III, and Ron Alterovitz, “**Motion planning for active cannulas**,” in *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Oct. 2009, pp. 801-806.

Lisa A. Lyons, Robert J. Webster III, and Ron Alterovitz, “**Planning Active Cannula Configurations Through Tubular Anatomy**,” in *Proc. IEEE International Conference on Robotics and Automation (ICRA)*, May 2010, pp. 2082-2087.

Keywords

medical robotics; motion planning; path planning; minimally invasive surgery; tentacle-like robots; procedure planning

For More Information

Ron Alterovitz

Phone (919) 962-1768

E-mail: ron@cs.unc.edu

<http://robotics.cs.unc.edu>