Concentric Tube Robotics for Minimally Invasive Neurosurgery

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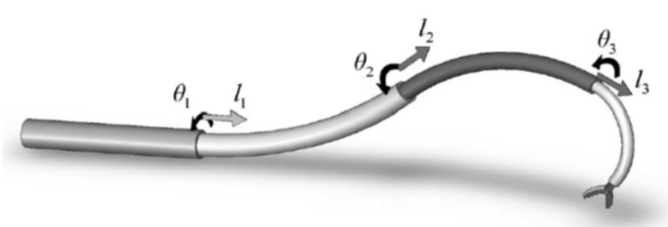
Introduction

Current minimally invasive neuroendoscopic approaches remain largely linear, relying on a direct path from the cranial entry point to the surgical workspace. Highly flexible, minimally invasive navigation within the intracranial space is an unmet challenge. Recent innovations in concentric tube robotics represent an exciting potential solution to this navigation challenge [1-4]. Concentric tube robots are constructed from telescoping curved tubes with cross sections comparable to catheters and needles. Translation and rotation of their individual tube segments creates precise snake-like motions. These tube lumens are capable of delivering flexible endoscopic systems and a wide spectrum of wires and articulated tip-mounted tools. We present a novel concentric tube robot prototype capable of delivering multimodality fiber based surgical instrumentation to intracranial surgical targets.

Concentric Cannula Concept

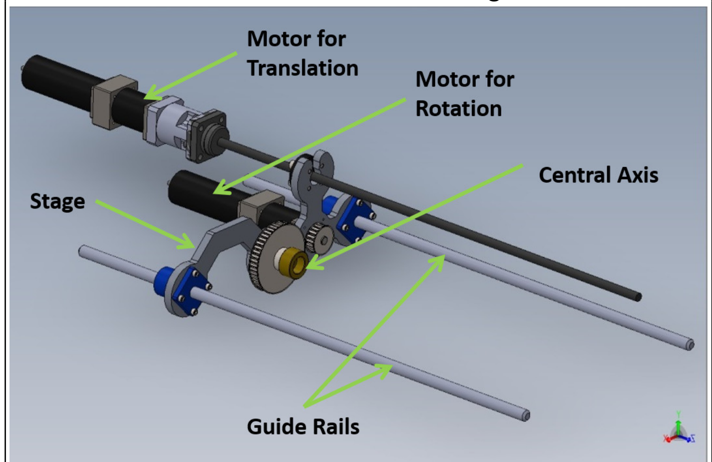


Independently controlling the tranlsation and rotation of concentrically combined curved tube segments allows complex non-linear motion.[4]

Methods

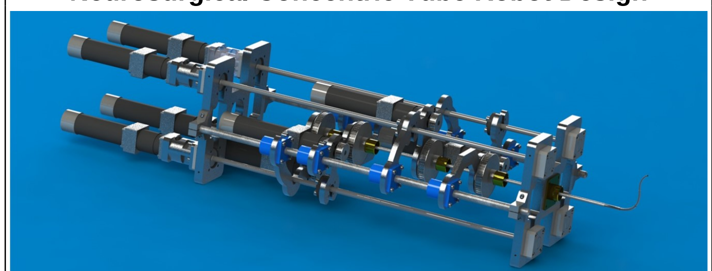
Design specifications for a concentric tube robot capable of minimally invasive intracranial navigation were developed. From this design, a robot prototype was successfully manufactured. A series of navigation and point position accuracy tests were performed by the robot using randomly generated target points and trajectories within an ex vivo workspace.

Curved Tube Drive Stage



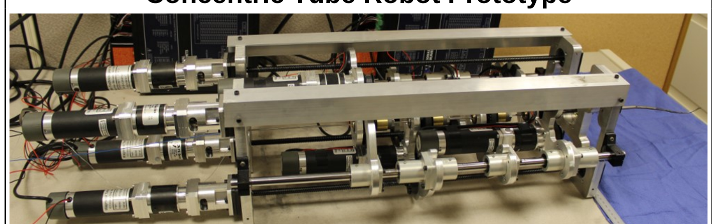
Precision motors, attached to lead screws, drive translation and rotation of the tube mounted in the central axis.

Neurosurgical Concentric Tube Robot Design



A four-tube robot was designed through modular combination of stages.

Concentric Tube Robot Prototype



A force-feedback controller interfaced with a novel control software allows the robot to perform precise, smooth motions.

Results

A novel concentric tube robotic platform was created consisting of four independently controllable concentric, pre-curved nitinol cannulas. Robotic control software was created to allow cannula steering via an intuitive graphical user interface and force-feedback controller. Point position accuracy and trajectory tracking studies under visual feedback guidance demonstrated robot precision to be within 1mm (root mean square error <1mm).

An operator-controlled sequential point-touch experiment demonstrates navigation accuracy.

Conclusions

We have successfully developed a novel neurosurgical concentric tube robot system capable of precise, complex and non-linear motions. Serving as a highly controllable flexible working channel, this system stands to augment capabilities for delivering flexible imaging and surgical instrumentation via non-linear intracranial trajectories.

References

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[4] T. Anor, J. Madsen and P. Dupont. Algorithms for Design of Continuum Robots Using the Concentric Tubes Approach: A Neurosurgical Example. 2011 IEEE International Conference on Robotics and Automation, May 9-13, 2011, Shanghai, China