

Project 2 Background Reading Report: Design and Modeling of a Compact Advancement Mechanism for a Modified COAST Guidewire Robot

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1. Introduction

Here I am going to introduce a series of works of the COaxially Aligned STEerable (COAST) guidewire robot to perform follow-the-leader (FTL) motion. I will focus on the paper “*Design and Modeling of a Compact Advancement Mechanism for a Modified COAST Guidewire Robot*”^[1] published in 2022 IEEE International Conference on Robotics and Automation by Patrick Lis et al., which proposes a compact guidewire advancement mechanism that is able to dispense guidewires up to 150 cm in length. This research is conducted under Prof. Desai at the Georgia Institute of Technology. I will also give a glance at their prior and further works.^[2, 3, 4]

Peripheral vascular intervention (PVI) remains a challenging procedure mainly due to the tortuosity of the vessels needing to be traversed by guidewires and catheters. PVIs often involve the placement of a guidewire as a first step. Superelastic nitinol wires display high strain recovery, thus allowing repeated high curvature bends with minimal damage to the device.^[5]

Based on their prior work, a tendon-driven guidewire consists of tubes that are actuated using nitinol wires, or “tendons”, that when pulled, can bend a flexible region near the distal end of the tube, hence allowing steering capability at the tip.^[2] To traverse vasculature with high angulation without causing trauma to the vessel walls, the COAST guidewire was then developed with the ability to vary the bending segment length, allowing navigation through phantom vasculature with different curvatures.^[3] Using this mechanism, the robotic guidewire can perform FTL motion by keeping a constant curvature along the bending segment of the guidewire.

In addition to maneuvering through tortuous vessels, guidewires need to travel great lengths to reach target areas. The major contribution of this work is to develop a compact advancement mechanism consisting of a spool that coils various sizes of nitinol guidewires with the capability of feeding and retracting the guidewire accurately. ^[1]

After this paper, the research group detail the kinematic mapping of the COAST, develop an analytical Jacobian model to perform velocity kinematics, and implement Jacobian-based control to demonstrate FTL motion of the guidewire in free space. ^[4]

2. Technical summary

2.1. Modified COAST Guidewire Robot

A prototype of the modified COAST guidewire robot is constructed using three nitinol components. An “external tube”, made of superelastic nitinol, is designed with rectangular unidirectional asymmetric notches to manufacture a compliant joint with a bending segment length of 75 mm. The depth of cut was determined to be 71.04% of the outer diameter, offering a highly compliant bending segment. Within the external tube, an “internal tube”, also made of nitinol, is placed to adjust the bending segment length as it is retracted or advanced within the external tube. Within the two tubes, a nitinol wire (Diameter: 0.076 mm) is fixed at the distal tip of the external tube where it can be actuated to achieve a desired curvature.

With this structure, the guidewire can be comprised of a ‘bending segment’ and a ‘non-bending segment’, where the former is comprised of only the external tube and tendon and latter comprised of all three components. Actuation of the tendon results in a constant curvature profile of the bending segment in the plane of the asymmetric notches as the non-bending segment remains rigid due to the added stiffness of the internal tube. The position of the internal tube dictates how long the bending segment length is while tendon stroke controls the angle of the bending segment joint. The external tube is fixed within the compact guidewire advancement mechanism, while the internal tube independently retracts or advances within the external tube.

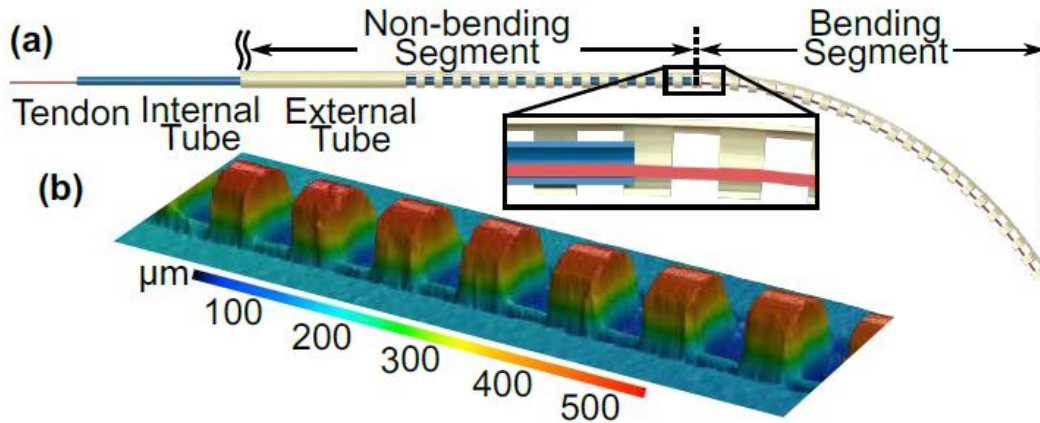


Figure 1: (a) Modified COAST Guidewire assembly;
 (b) 3D laser-scanned profile of the external tube. ^[1]

2.2. Compact Guidewire Advancement Mechanism

The modified COAST guidewire is placed into a 3D-printed spool that contains a compact actuation mechanism within to execute desired navigation of the guidewire tip. For the design to remain as compact as possible, the outer diameter of the spool was experimentally determined to be 10 cm. This allows for typical sizes of nitinol guidewires to be coiled around the spool without kinking while allowing all of the internal components to be nested within it.

The guidewire is lead into the spool via a hole 3D-printed within the outer wall of the spool, where a clamp fixes the proximal end of the external tube using bolts, while allowing the internal tube to freely move within it. Following the external tube clamp, the internal tube is passed into the internal tube roller mechanism that controls the bending segment length, X_b . This action is done using a friction based roller mechanism that utilizes a dual component roller system. The internal tube rests on an aluminum rod driven by a DC motor, while a 3D-printed free rotating wheel is clamped down onto the aluminum rod using a screw at the exit point of the roller to maintain the right amount of friction between the two rolling segments.

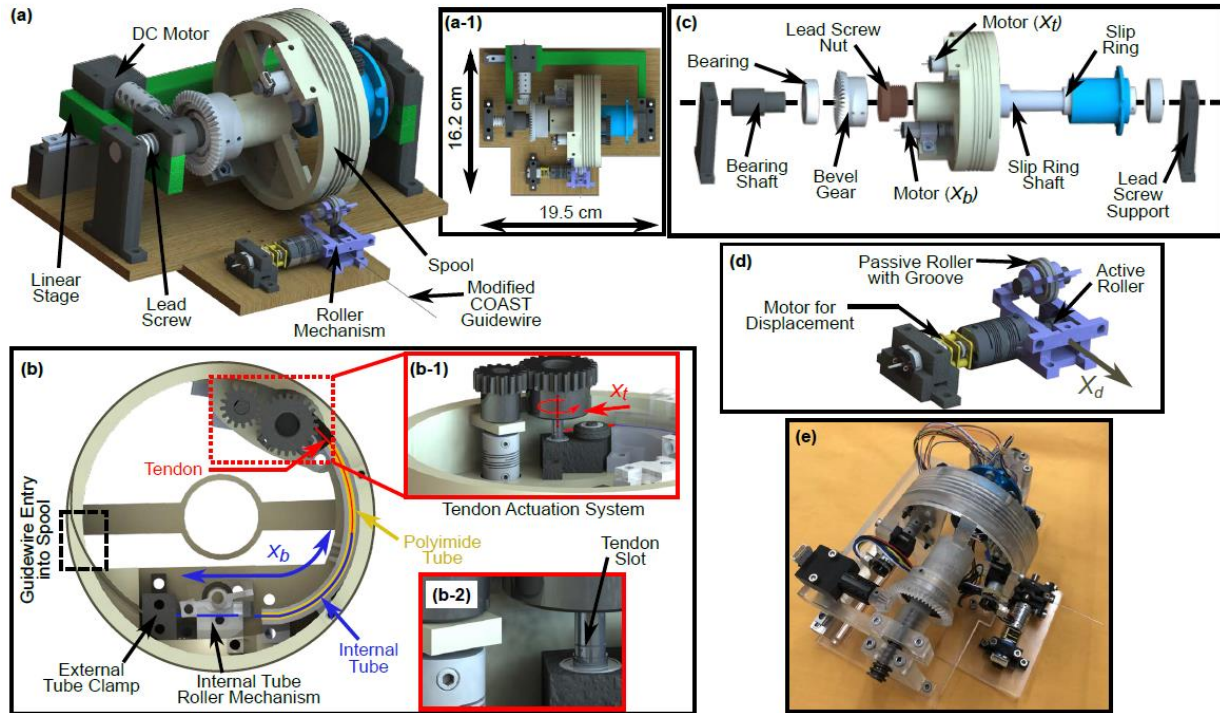


Figure 2: The compact guidewire advancement mechanism ^[1]

2.3. Bending Joint Model and ex vivo Demonstration

The capabilities of the modified COAST guidewire, using the advancement mechanism, are demonstrated by navigation through an ex vivo porcine aorta. Circular arcs were fit for each of the outer walls of the porcine aorta to determine the corresponding radius of curvature, which was then averaged to determine the radius of curvature of the centerline of the vessel.

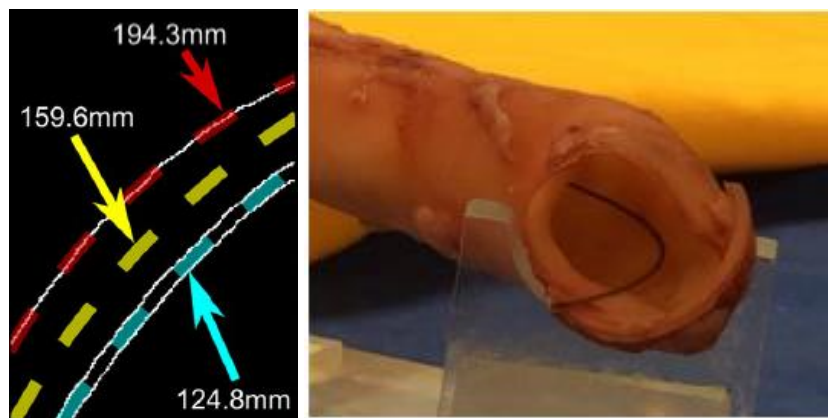


Figure 3: Experimental setup for ex vivo demonstration ^[1]

3. Discussion

Our project focuses on a continuum robot to conduct retinal surgery, while this series of works is about a concentric robot COAST to deliver the peripheral vascular intervention. Both are designed to move through and manipulate their environment. They share some similarities in terms of their structure and mechanics, such as the use of flexible materials (nitinol) and the ability to bend and twist in multiple directions. Also, their workflow, designing an end-effector (tendon), developing a robot platform (COAST), optimizing the system performance, and conducting a Jacobian-based model and control, is an excellent example for us.

Nevertheless, the kinematic model and advancement mechanism are completely different. The continuum prototype utilizes one rotational motor to control the body shape, one linear motor to realize precise translation, and integrates with the SHER system to achieve large-range motion. But the advancement system mentioned is still a good inspiration for the design to lengthen the available operation area.

The paper has a main drawback. The research group aims to develop an automation system for the guidewire at the very beginning of the series. However, they just realize an open-loop control and a visual-feedback system by the end of this paper, which still relies on the trained surgeons rather than the algorithm itself.

Reference

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