Proceedings of the 2023 Design of Medical Devices Conference
DMD2023
April 17-19, 2023, Minneapolis, MN, USA

DMD2023-1659

MINIMALISTIC DESIGN OF AN ACTUATION DEVICE TO MANIPULATE AN ACTIVE FLEXIBLE ROBOTIC TOOL

Samuel Lafreniere **Kyle Tran** **Bardia Konh**[1]
Department of Mechanical Engineering, University of Hawaii at Manoa
Honolulu, HI

ABSTRACT

This work presents a minimalistic design of an actuation system to operate an active flexible robotic tool to steer within tissue for precise targeting. The device is designed to be held by hand or installed on a robotic system. The robotic tool is operated based the user's commands received from a joystick button. Two internal tendons, actuated by two Maxon motors, realize precise bidirectional bending at the tip of the robotic tool. The flexible robotic tool is intended to facilitate manipulations in needle-based interventions such as prostate biopsy and brachytherapy.

Keywords: Actuation device, flexible robotic tool, precise manipulation

1. INTRODUCTION

Several therapeutic and diagnosis procedures such as brachytherapy, biopsy, and thermal ablation are now performed using active and flexible robotic tools under medical imaging modalities such as ultrasound (US), computer tomography (CT), or magnetic resonance imaging (MRI). Precise movement, navigation, and targeting accuracy of the robotic tools are among defining factors for success. Research efforts, in last decade, have been focused to improve robotic tools as well as visualization of both the tools and the tissue.

To improve flexibility of the robotic tools, our group has previously presented 3D printed shape memory alloy (SMA)-activated tools [1]–[3] for precise navigation inside tissue. We have also presented kinematic and dynamic analyses of the tools [4], [5] for proper positioning control based on self-sensing capabilities of the embedded SMAs. In other works, we presented a tendon-driven active needle to improve needle's navigation in procedures such as prostate brachytherapy [6], [7] or biopsy [8], [9]. To improve imaging and visualization, we have previously presented a robot-assisted ultrasound tracking (R-AUST) [10] to obtain the needle tip in real time inside tissue. In other works, 3D shape of the needle estimation [11] as well as the magnitude of the tissue movement [12] were estimated using US images to assist in robotic control of the needle inside tissue.

This work first presents an active flexible robotic tool, recently designed, and fabricated in our lab for bidirectional manipulation in precautious procedures. An actuation device is then designed and developed to operate the flexible robotic tool to control the tip movement based on the user's commands. The actuation device is intended to be small and handheld for potential use in needle-based interventions (instead of straight passive needles currently in practice), when tip manipulation is required. For example, the device could be installed behind the template, typically used in prostate brachytherapy, for use of active steerable needles when actuation and bending is required for the needle to follow a curved trajectory towards the target.

2. MATERIALS AND METHODS

2.1. Active Flexible Robotic Tool

Design of the active flexible robotic tool features an 8.92mm long compliant flexure section (shown in Figure 1a) for bidirectional bending. The flexure section is actuated via two internal tendons (nitinol wires of 0.13mm diameter). In this work, "bidirectional bending" indicates a 1DOF angular bending towards the two tendons on opposite sides. The robotic tool is fabricated on a superelastic nitinol tube (Johnson Matthey, London, UK) with an outer and inner diameter of 2.00 and 1.70mm, respectively, and tube thickness of 0.15mm. Six notches are carved on the nitinol tube on left and right sides to create a compliant flexure section with bidirectional bending capabilities. The notches are made in the lab using conventional machining tools such as a Dremel, and ultra-thin cut-off discs (Gesswein & Co., Inc., Bridgeport, Connecticut).

The planar bidirectional bending is realized via actuation (pulling) of Tendons 1 and 2 that are installed inside the tube on opposite sides. Next section describes the actuation system that

---

[1] Contact Author: konh@hawaii.edu

enables robotic control for the desired (output) bending angle based on the user's input.

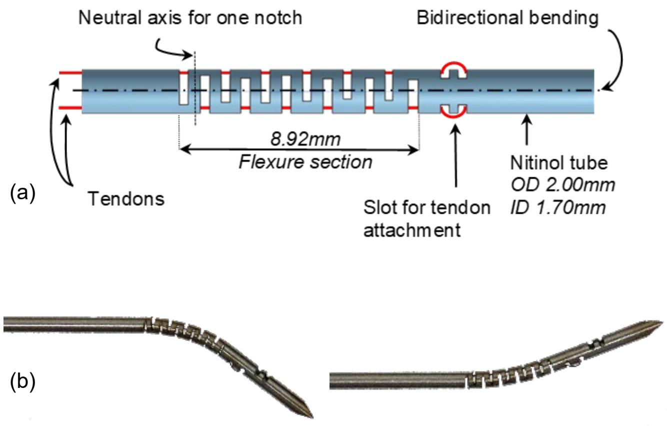

FIGURE 1: (a) TENDON-DRIVEN BIDIRECTIONAL ROBOTIC TOOL AND ITS COMPLIANT FLEXURE SECTION, AND (b) FABRICATED TOOL IN BENT POSITION VIA ACTUATION OF TENDONS 1 AND 2, RESPECTIVELY.

2.2. A Minimalistic Design of an Actuation Device

A minimalistic and easy to use actuation device is presented in this section to enable operation of the active flexible robotic tool (described in Section 2.1) based on the user's commands. The actuation device is designed with as small number of parts as possible to ensure light weight for handheld operation while also providing the ability to steer the robotic tool with a single hand.

Figure 2a shows the actuation device consisting of two similar combinations of a 0.5W Maxon DC motor RE 8 Ø8 mm, Precious Metal Brushes with an 8mm diameter lead screw drive (GP 8 S Ø8mm, Metric spindle, M3 x 0.5), and an encoder (MR, Type S, 100CPT) installed on two motor retainers to pull the two internal tendons upon actuation commands. The actuation commands are received from the user via a joystick button installed on a joystick retainer at the backside of the device. The flexible robotic tool is mounted on a retainer in the frontside of the device. The actuation system (shown in Figure 2b) is enclosed in a cylindrical casing. The parts were printed using Prusa i3 MK3 printer (Prusa Research, Prague, Czech Republic).

For each Maxon motor (shown in Figure 2b), two holders are designed to hold the motor and the lead screw. The first holder (housing the spindle on the lead screw) is mounted on a linear rail guide to translate rotational movement of the motor shaft to linear movement. The second holder is stationary, keeping the position of the motor. The holders are designed to ensure that all the movement occurs on the same plane. The free end of the tendon is fixed on the first holder. The tendon is threaded through the midpoint of the holder to ensure colinear movement.

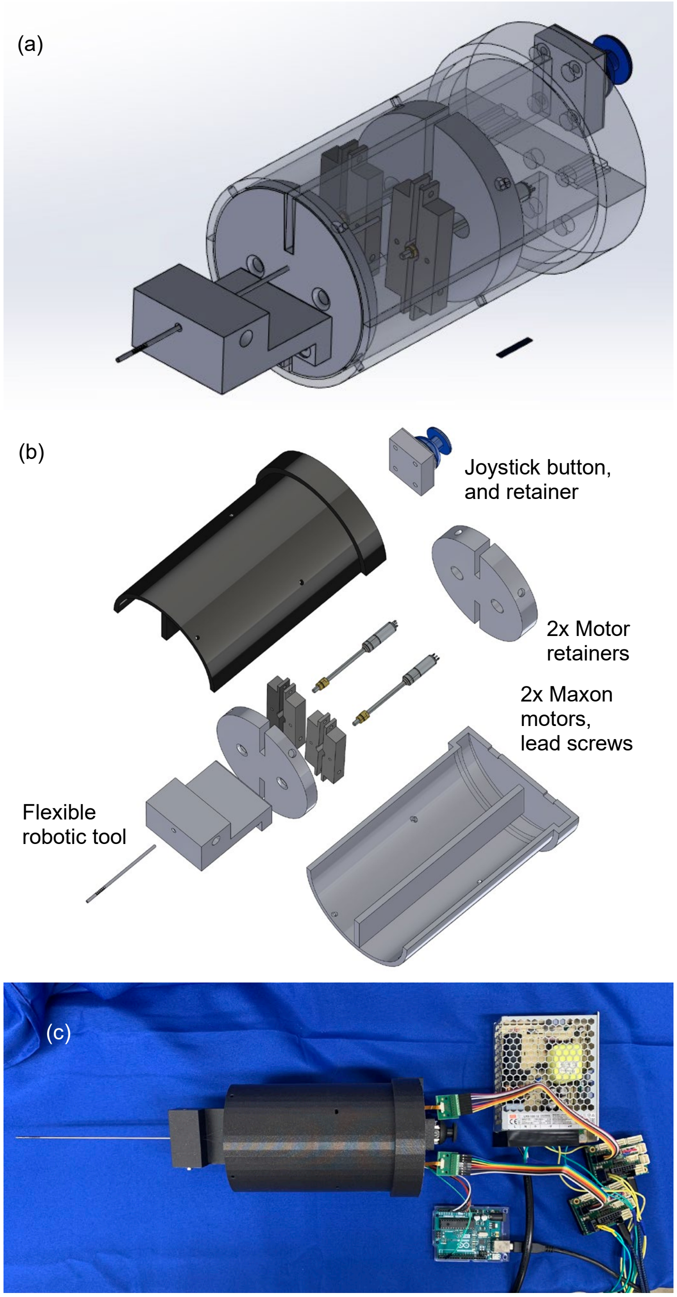

FIGURE 2: (a) COMPACT ACTUATION DEVICE (20MM SCALE BAR) WITH (b) LABELED PARTS IN EXPLODED VIEW, AND (c) FABRICATED PROTOTYPE.

2.3. Semi-Automated Actuation and Control

A semi-automated actuation and control (shown in Figure 2c) is presented in this section to manipulate the tip of the tool at a desired bending angle.

A program is coded on a raspberry Pi that executes at runtime. The functional block diagram is shown in Figure 3. A DualShock 4 controller, commonly used with the Playstation 4 video game console, henceforth called the 'joystick', interfaces with the computer via bluetooth. The computer interfaces with two EPOS

4 controllers via separate microUSB-to-USB connections. Each EPOS 4 controller interfaces directly with a Maxon motor, designated as left and right in the figure, via wired connection.

The code is entirely constructed in Python, using CTypes, a foreign library conversion tool, to convert the EPOS Command Library from C to a Python-friendly format. PyGame is utilized to interface between the operator and the code.

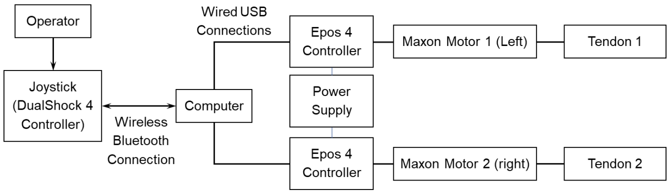

FIGURE 3: FUNCTIONAL BLOCK DIAGRAM FOR JOYSTICK USER CONTROLLER.

3. RESULTS AND DISCUSSION

To evaluate the capability of the robotic tool to produce sufficient bidirectional bending to reach the target positions inside prostate gland, an experimental setup (shown in Figure 4) was developed with assigned target positions inside a pelvis male model (hBARSCI, Rochester, NY). The prostate phantom was modeled after a patient's prostate that was obtained from the Cancer Imaging Archives [13]. The targets were 3D printed and mounted inside the pelvis model to represent with reasonable geometric relationships. It was shown that the range of motion provided by the bidirectional bending of the robotic tool is sufficient to cover the marked targets (spheres on the endpoints of the 3D print). The targets were randomly generated to demonstrate the workspace of the bidirectional needle.

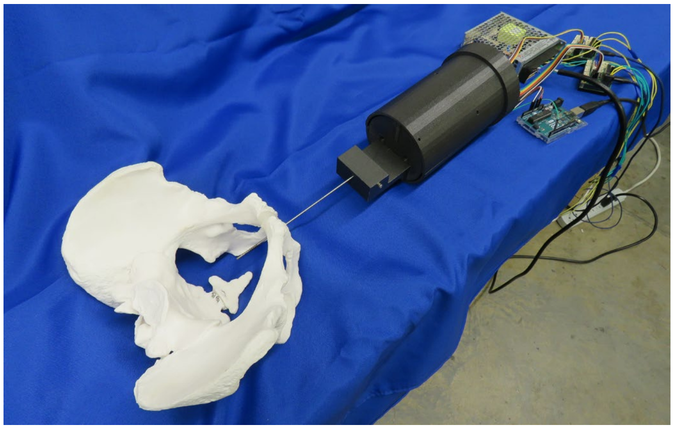

FIGURE 4: APPLICATION OF THE FLEXIBLE ROBOTIC TOOL FOR PROSTATE INTERVENTIONS.

4. CONCLUSION

This work presents an actuation system to operate an active tendon-driven flexible robotic tool. The actuation device realizes a desired angular bending (in two directions) based on the user's commands received from a joystick button. The device features a minimalistic design with as few parts as possible to present a light-weight and portable actuation system. Future work intends to develop a compact version of this device for handheld operations and ease of utilization.

ACKNOWLEDGEMENTS

Research reported in this publication was supported by the National Institute Of Biomedical Imaging And Bioengineering of the National Institutes of Health under Award Number K25EB030562. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

REFERENCES

[1] Z. K. Varnamkhasti and B. Konh, "Design, Fabrication, and Testing of a Flexible Three-Dimensional Printed Percutaneous Needle with Embedded Actuators," *ASME J. Med. Devices*, vol. 15, no. 2, p. 021007 (10 pages), 2020.

[2] Z. K. Varnamkhasti and B. Konh, "Compact 3D-Printed Active Flexible Needle for Percutaneous Procedures," *Surg. Innov.*, vol. 27, no. 4, pp. 402–405, 2020, doi: 10.1177/1553350620945564.

[3] B. Padasdao and B. Konh, "Shape Memory Alloy Actuators in an Active Needle - Modeling , Precise Assembly, and Performance Evaluation," *J. Manuf. Sci. Eng.*, vol. 143, no. 2, p. 021003 (10 pages), 2020.

[4] S. Karimi and B. Konh, "Self-Sensing Feedback Control of Multiple Interacting Shape Memory Alloy Actuators in a 3D Steerable Active Flexible Needle," *J. Intell. Mater. Syst. Struct.*, vol. 31, no. 12, pp. 1524–1540, 2020.

[5] S. Karimi and B. Konh, "Kinematics Modelling and Dynamics Analysis of an SMA-Actuated Active Flexible Needle for Feedback-Controlled Manipulation in Phantom," *Med. Eng. Phys.*, vol. 107, p. 103846, 2022.

[6] B. Konh, B. Padasdao, Z. Batsaikhan, and J. Lederer, "Steering a Tendon-Driven Needle in High-Dose-Rate Prostate Brachytherapy for Patients with Pubic Arch Interference," in *International Symposium on Medical Robotics (ISMR)*, 2021, pp. 1–7.

[7] B. Padasdao, Z. Batsaikhan, S. Lafreniere, M. Rabiei, and B. Konh, "Modeling and Operator Control of a Robotic Tool for Bidirectional Manipulation in Targeted Prostate Biopsy," in *International Symposium on Medical Robotics (ISMR)*, 2022, pp. 1–7.

[8] B. Padasdao, S. Lafreniere, M. Rabiei, Z. Batsaikhan, and B. Konh, "Teleoperated and Automated Control of a Robotic Tool for Targeted Prostate Biopsy," *Jounral Med. Robot. Res.*, 2023, doi: 10.1142/S2424905X23400020.

[9] B. Padasdao, Z. K. Varnamkhasti, and B. Konh, “3D Steerable Biopsy Needle with a Motorized Manipulation System and Ultrasound Tracking to Navigate inside Tissue,” *J. Med. Robot. Res.*, vol. 05, no. 03n04, pp. 2150003-1-2150003–18, 2021, doi: 10.1142/S2424905X21500033.

[10] B. Konh, B. Padasdao, Z. Batsaikhan, and S. Y. Ko, “Integrating robot-assisted ultrasound tracking and 3D needle shape prediction for real-time tracking of the needle tip in needle steering procedures,” *Int. J. Med. Robot. Comput. Assist. Surg.*, vol. 17, no. 4, p. e2272, 2021, doi: 10.1002/rcs.2272.

[11] B. Konh, Z. Batsaikhan, and B. Padasdao, “3D shape estimation of an active needle inside tissue using 2D ultrasound images,” in *Design of Medical Devices Conference*, 2021, pp. 1–4.

[12] B. Padasdao, Z. Batsaikhan, D. Brown, and J. Moore, “Estimation of tissue movement in needle insertion tasks using an active needle,” in *Design of Medical Devices Conference*, 2022, pp. 1–5.

[13] “Prostate MRI and Ultrasound With Pathology and Coordinates of Tracked Biopsy (Prostate-MRI-US-Biopsy) - The Cancer Imaging Archive (TCIA) Public Access - Cancer Imaging Archive Wiki.” .