NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Engineering Cybernetics

MASTER'S THESIS ASSIGNMENT

Name of candidate: Katla Maria Gudmunsdottir
Topic: Engineering Cybernetics
Title (English): Closed-Loop Navigation of a Ribbon-Shaped Robotic Device in Brain Tissue
Title (Norwegian): Lukket-sløyfe-navigering av en båndformet robot i hjernevev

Motivation

Navigating biomedical instruments inside the brain remains challenging and high-risk. Robotic-assisted surgery has transformed many fields, but its application in neurosurgery remains limited by current technology [1]. The traditional rigid instruments are restricted in the their ability to navigate delicate and structurally complex soft tissues such as the brain [2]. Steerable, flexible devices offer a potential solution, improving access and safety while enabling new procedures [3]. Additionally, advancements in microfabrication have enabled the production of microscopic probes capable of monitoring biological activity and delivering stimulation or therapy [4], [5]. Yet, no steerable device has been developed that can both navigate brain tissue and utilize this technology for real-time sensing and targeted therapy.

Context

To address this unmet need the MICROBS lab has developed a novel ribbon-shaped, tendon-driven continuum microrobot for minimally invasive neurosurgical interventions. This design allows for agile 3D navigation by achieving configuration unattainable by traditional rod-like instruments [2]. Enabling precise navigation through soft tissue, capable of safely avoiding critical structures and reaching multiple targets in a single insertion. However, this unique geometry introduces new challenges in modeling and control, requiring specialized solutions.

Assignment

The aim of this master thesis is to develop a closed-loop control system for this novel robotic device by integrating real-time 3D tip tracking, path planning and navigation in order to enable precise and adaptive movement in minimally invasive neurosurgical applications. The work will be structured into two main areas:

<u>System Integration and Code Refinement</u>

1. Establish a robust codebase: Restructure and optimize the code for readability, testability and scalability.

2. Interface with the 3D tip tracking algorithm: Establish a robust connection between the Python-based tip tracking system and the C++/Qt-based control system to enable real-time feedback.

3. Integrate path planning: Incorporate the existing 2D path-planning algorithm and modify it such that it can be used as the reference path for 2D control.

<u>Control System Development</u>

4. Enhance tendon-driven actuation: Improve individual tendon tension control for better precision and stability.

5. Develop closed-loop 2D navigation: Implement a control system to minimize the error between the microrobot's path and the planned trajectory.

6. Develop closed-loop 3D navigation: Extend the control framework to support full three dimensional movement.

Assignment given: 13. February 2025
Submission deadline: 17. July 2025

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[2] L. Noseda, A. Liu, L. Pancaldi, and M. S. Sakar, "A Flat Tendon-Driven Continuum Microrobot for Brain Interventions," in 2024 IEEE International Conference on Robotics and Automation (ICRA), Yokohama, Japan: IEEE, May 2024, pp. 13466–13471. doi: 10.1109/ICRA57147.2024.10611399.
[3] T. da Veiga et al., "Challenges of continuum robots in clinical context: a review," Prog. Biomed. Eng., vol. 2, no. 3, p. 032003, Jul. 2020, doi: 10.1088/2516-1091/ab9f41.
[4] R. Chen, A. Canales, and P. Anikeeva, "Neural recording and modulation technologies," Nat. Rev. Mater., vol. 2, no. 2, pp. 1–16, Jan. 2017, doi: 10.1038/natrevmats.2016.93.
[5] J. A. Frank, M.-J. Antonini, and P. Anikeeva, "Next-generation interfaces for studying neural function," Nat. Biotechnol., vol. 37, no. 9, pp. 1013–1023, Sep. 2019, doi: 10.1038/s41587-019-0198-8