Closed-Loop Navigation of a Ribbon-Shaped Robotic Device in Brain Tissue

NTNU Supervisor:	*Øyvind Stavdahl*	*oyvind.stavdahl@ntnu.no*
EPFL Supervisors:	*Selman Sakar*	*selman.sakar@epfl.ch*
	Lorenzo Noseda	*lorenzo.noseda@epfl.ch*
Project Type:	*Master Thesis*	
Section:	*NTNU Cybernetics and Robotics*	
Official Start Date:	*13.02.2025*	
Submission of Final Report:	*TBD*	

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:

System Integration and Code Refinement

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.

Control System Development

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.

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