Reinforcement-Learning based Catheter Trajectory Generation for Bioelectric Navigation

Project Management and Software Development
for Medical Applications

General Info

Contact Person: Heiko Maier

Contact Email: heiko.maier@tum.de

Project Abstract

Catheterization procedures for treatment of diseases of the human vascular system require harmful radiation doses and application of contrast agent to the patient. We intend to improve a new catheterization concept, “Bioelectric Navigation”, by creating a realistic simulation pipeline based on electrical and mechanical simulators and reinforcement learning agents.

Background and Motivation

In order to successfully treat diseases of the human vasculature, current catheterization procedures require guidance using x-ray radiation, which causes harmful radiation doses, and administration of potentially nephrotoxic contrast agents. A different and novel approach that is being investigated by the CAMP chair is Bioelectric Navigation [1], which relies on electrical sensing of the position inside the human vasculature.

For refining this type of navigation, a pipeline to simulate electrical signals from a catheter inside a blood vessel has been built, with the aim to generate realistic signals on which potential localization algorithms and different sensing configurations can be tested. Currently, the pipeline is missing a way to simulate the realistic motion and deformation of a catheter during an intervention. The core idea of the given project is to use an existing reinforcement learning (RL) framework, for training an agent on a mechanical catheterization simulator (e.g. [2]) to navigate a given vasculature, thereby generating exemplary catheter trajectories and catheter deformations. Once these have been generated, the corresponding electrical signals along these trajectories can be simulated using the existing electrical simulation pipeline and used for training of localization algorithms, evaluation of different sensing configurations, and similar tasks.

Student’s Tasks Description

In a first step, the student will compare two popular mechanical simulators with applications to catheterization procedures [2,3], and get an overview over existing reinforcement learning frameworks for catheterization using these simulators (e.g. [1]).

After choosing a framework, the student will either use an existing, pre-trained reinforcement learning agent or train one with the given framework on a target vascular anatomy. Once a successfully trained agent is capable of navigating the vasculature, the student will search for a way to integrate the existing electrical simulation into the pipeline, either by exporting the generated trajectories and catheter shapes or directly coupling the mechanical and electrical simulator. This will allow to simulate realistic Bioelectric Navigation signals based on the RL-agent’s navigation and the mechanical simulator.

Please send the completed proposal to ardit.ramadani@tum.de, lennart.bastian@tum.de and tianyu.song@tum.de. Please note that this proposal will be evaluated by the BMC coordinators and will be assigned to a student only in case of acceptance.

Depending on the progress and interests of the student, further topics that can be explored at this stage are to use the simulated signals to train a localization network, to explore different electrical sensing configurations, or to try and train an RL agent to navigate solely based on the bioelectric signals. Depending on the progress of the project and the student's motivation, this PMSD project can later be expanded into a Master's Thesis.

In completing the given project, the student will learn to use both mechanical and electrical simulators to simulate medical interventions in the form of catheterization procedures. They will collect hands-on experience in the field of reinforcement learning for (autonomous) catheterization, and the interesting topic of learning on simulated data.

Technical Prerequisites

- Required: Python
- Strong plus: C++
- Beneficial: Knowledge in Reinforcement Learning (theoretical and/or applied). Experience with SOFA and/or MuJoCo simulator. Knowledge and/or interest in catheterization/ endovascular procedures.

References

[1] Sutton, E.E., Fuerst, B., Ghotbi, R. *et al.* Biologically Inspired Catheter for Endovascular Sensing and Navigation. *Sci Rep* 10, 5643 (2020). https://doi.org/10.1038/s41598-020-62360-w

[2] Jianu, T., Huang, B., Abdelaziz, M.E., Vu, M.N., Fichera, S., Lee, C.Y., Berthet-Rayne, P. and Nguyen, A., 2022. CathSim: An Open-source Simulator for Autonomous Cannulation. *arXiv preprint arXiv:2208.01455*.

[3] François Faure, Christian Duriez, Hervé Delingette, Jérémie Allard et al.: SOFA: A Multi-Model Framework for Interactive Physical Simulation. *Soft Tissue Biomechanical Modeling for Computer Assisted Surgery*, 2012