Final Defense

PhD Alberto Favaro

PhD Marco Vidotto

June 22nd 2020 - h: 14.30

Aula Seminari – Schiavoni

Modalità Teleconferenza Microsoft Teams

PhD student: ALBERTO FAVARO – XXXI Cycle

Thesis title: Optimized curvilinear path planning and pose estimation for a programmable bevel-tip needle in Keyhole neurosurgery

Advisor: Prof. **ELENA DE MOMI – FERRIGNO GIANCARLO – RODRIGUEZ Y BAENA**

Abstract:

Over the last decades, a great interest has been showing towards the development of flexible steerable needles in minimally invasive surgery. These needles feature a complex kinematics that hinders the possibility to plan the insertion trajectories unless with the aid of an automatic path planner. Solutions proposed in literature for automatic steerable needle path planning in 3D focus either on a fast computation to allow the interactive re-planning or on path optimality at the expense of a high computational time.
The needle motion plan can be executed by a robotically-assisted insertion platform. During the needle insertion, the control system needs to know the needle position and orientation in order to address for possible needle torsion that has been experimentally proven to afflict percutaneous needles undermining the insertion accuracy. Because of the thin needle diameter, current tracking systems cannot sense the torsion of the needle about its insertion axis.
On this background, the overall goal of this PhD thesis is to describe a preoperative curvilinear path planner for steerable needles and to design a solution for estimating the needle tip position and orientation (i.e. the full pose) during the insertion.
In particular, the contributions of this PhD work are:
1. A pre-operative curvilinear path planner for steerable needles able to solve the planning problem computing a kinematically-feasible path. The planner optimizes the solution according to the criteria of minimum path length and maximum obstacle clearance keeping the computational time consistent with standard pre-operative planning algorithms. To contextualize the planning problem with respect to the state of the art, a literature review on path planning for steerable needles is reported, with a focus on the widely used sampling-based methods. A pre-operative curvilinear path planner is then presented. Through a bespoke evolutionary optimization, the planner can maximize the obstacle avoidance while minimizing the path length. In addition, by defining the subspace of reachability of the needle and confining the path search within this region, the algorithm achieves a computational time consistent with standard pre-operative planners. The solution was validated through multiple simulated needle insertions in a neurosurgical scenario.
2. An on-line pose estimation solution for a multi-segment steerable needle using position measurement from sensors mounted on the needle tip. A solution for the accurate estimation of the needle pose is presented, based on the kinematic model of the needle and position tracking data. The position of the needle segment tips are retrieved by electromagnetic sensors and used by a kinematic-based prediction method to correct the needle state estimation and infer the angle of needle torsion. The method was tested on a two-segment steerable needle in simulation and in phantom-brain gelatine. A reliable and robust estimation was demonstrated with position and orientation errors consistent with the state of the art. The solution was later extended to a four-segment needle. Ingel validation shown the feasibility of the method although, in the latter
case, a long time of convergence was evidenced for the torsion angle. The Programmable Bevel-tip Needle (PBN) is a multi-segment steerable needle under development within the EU EDEN2020 project. It is composed by four axially-interlocked slender sections, robotically actuated to develop specific tip configurations that allow the needle to steer in the space. In this PhD dissertation, the PBN is considered as case study for the presented methods.

PhD in Bioengineering Final Defense

POLITECNICO MILANO 1863

PhD student: MARCO VIDOTTO – XXXII Cycle

Thesis title: A combined experimental and numerical approach towards a comprehensive drug delivery model

Advisor: Prof. **ELENA DE MOMI – DANIELE DINI**

Abstract:

Convection-Enhanced Delivery (CED) has been recently introduced as a promising surgical technique to bypass the blood-brain barrier and inject a chemotherapeutic agent directly in the brain tissue (Jahangiri et al., 2016). CED can be used for treating different kind of diseases, from brain tumor to Parkinson and epilepsy (Mehta et al., 2015; Christine et al., 2019; Rogawski, 2009). Although this technique was expected to be effective, especially against recurrent tumors, the clinical trials did not achieve the desired results in terms of life expectancy for the patients (Kunwar et al., 2010). A major impairment to progress is given by the fact that the cancerous areas are usually not reached by a sufficiently high concentration of drug. Indeed, since the brain is an anisotropic and heterogeneous porous medium, for the clinicians it is very difficult to set the infusion in the best way possible and often the drug misses the target area. To tackle this issue, researchers have worked on predictive numerical models that can offer the surgeons a simulation environment to test different infusion settings. Despite these models are extremely valuable, their predictive capability is still not sufficiently accurate thus preventing their use in standard clinical practice. For this reason, Vendel, Rottschäfer, and Lange, 2019 pointed out the paramount importance of having refined mathematical models on the spatial drug distribution within the brain whereas Nicholson and Hrabˇetová, 2017 and Holter et al., 2017 underlined the pivotal role of the brain microstructure.
This aspect, in particular, has been explored by limited researches and the relation between tissue microstructure and important fluid dynamics parameters is still controversial. In the present contribution, we develop an extensive study that starts from a detailed analysis of the brain microstructure, with particular emphasis on the white matter (WM) permeability, and finishes with the integration of the acquired information in a CED predictive model at the macroscale. In addition to the Introduction Chapter and the Conclusion Chapter, the dissertation is divided in four main research tracks. In the first (Chapter 2), we build a geometrical model of the WM considering its main geometrical characteristics, namely axon diameter distribution, extracellular space (ECS) volume fraction and ECS width. From this model, we extract two important information: the hydraulic permeability in three WMareas and the size of the representative volume element (RVE) to analyse to obtain reliable results. A three-dimensional version of the same geometrical model is also exploited, with a different methodological approach, to study the WM tortuosity, a very important parameter for drug diffusion. In the second (Chapter 3), we move towards a more realistic estimate of the permeability by analysing two WM areas (corpus callosum and fornix) starting from the acquisition of electron microscopy images of their microstructure. In this track, we demonstrate and quantified the anisotropic and heterogeneous behaviour of theWMwhich is a very important result because it helps shading light on this fundamental but still controversial parameter. These results are validated in the third track (Chapter 4) by means of an experimental campaign on ovine WM samples performed in collaboration with Imperial College London.
Finally, in the last track (Chapter 5), we integrate the information about the WM permeability, acquired in the previous Chapters with a relatively new imaging technique, namely the Neurite Orientation Dispersion and Density Imaging, to incorporate a more advanced and comprehensive description of the brain microstructure into a predictive computational model. We demonstrate the relevance of the work by showing the impact on the predicted drug distribution, which differs significantly from the state-of-the-art model in terms of distribution shape, concentration profile and infusion linear penetration length.

PHD COMMITTEE

Prof Stéphane Bordas	**Prof. Kaspar Althoefer**	**Prof. Simona Ferrante**
Professor in Computational Mechanics - University of Luxembourg	Director, Advanced Robotics @ Queen Mary (ARQ) Turing Fellow School of Engineering and Materials Science Queen Mary University of London	Politecnico di Milano Dipartimento di Elettronica, Informazione e Bioingegneria