External Internship

M.Sc. Medical Engineering – Track Medical Imaging

Research Proposal: "Semi-Automated Path Planning for Deep Brain Stimulation Surgery" (tentative)

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Deep brain stimulation (DBS) is a neurosurgical technique used to improve quality of life and reduce symptoms of some patients with e.g. Parkinson's disease, Tourette's syndrome or essential tremor. It involves implanting electrodes within certain deep regions of the brain, such as the sub-thalamic nucleus (STN) or globus pallidus (GPi), that produce electrical impulses to regulate abnormal neuronal activity. Implantation of these electrodes is accomplished via a complex surgical procedure, which is assisted by several medical imaging techniques such as CT and a range of MRI scans for path planning, using the stereotaxic framework. Interpretation of these images and the planning of an appropriate "path", being the path along which the electrodes are inserted from the skull to the target, is currently done manually in clinical practice. This process is done by neurosurgeons prior to the surgical procedure and proves to be quite time-consuming and labour-intensive. It involves the manual generation of a linear path to the defined target from the skull, taking into account critical structures such as blood vessels or ventricles. In practice, this process usually encompasses several steps of trial-and-error, in which anatomical scans are checked slice-by-slice for path collisions with these critical structures.

Clinically, an improvement of the DBS implantation process has been proposed to be the automation of the path planning process. Although implementation of such techniques was deemed to be infeasible in previous decades [1], recent literature suggests otherwise, mostly based on an increase in computational power and improvements in image segmentation techniques [2]–[11], with some even anticipating the rise of curvilinear path planning for robot-assisted surgery [12], [13]. Implementation in clinical practice, however, has not progressed much [2].

In this project, we aim to explore the possibilities of automated path planning for DBS surgery and to create a DBS path planning software tool, in cooperation with relevant clinicians. The technical implementation may be thought of as three separate parts, being the image registration, the segmentation of critical structures and the final determination of the optimal path.
Firstly, an image registration algorithm is used to register all MRI images to each other and to the pre-operative CT scan. This CT scan is performed with the stereotaxic frame attached, yielding the ability to transform all coordinates into stereotaxic coordinates. Additionally, this registration step enables the combination of the high geometric accuracy of the CT scan with the anatomic information retrieved from the MRI scans. Here, we will build upon previously done work regarding image co-registration, as has been implemented in widely used software packages such as *Freesurfer*, *FSL* or *ITK*.
The segmentation of critical structures, such as cerebral blood vessels or ventricles becomes important

when determining regions of the brain the path may not collide with, which would result in complications such as intra-operative bleeding. Here, critical structures will be defined as sulci (as it is known from anatomical studies that these tend to contain a high amount of blood vessels), ventricles and cerebral blood vessels above a to-be-defined size. The segmentation of the ventricles and sulci will likely be implemented based on freely available CSF segmentation techniques (such as *Freesurfer*) and some basic morphological operations. The segmentation of blood vessels, being the technically more challenging of the three, will be implemented based on recent work regarding this topic [14]–[26]. Here, the primary focus will be on non-machine learning based techniques, as it is hypothesised that these techniques will be easier to implement on our dataset without the need for large amounts of annotated data. An initial attempt will be made at the implementation of the Frangi vesselness-based *LevelSet* method [16], as it is relatively well documented, has been proven to work well for contrast enhanced T1-weighted MRI scans [14] and might enable the partial recycling of previously written software originally used for enlarged perivascular space segmentation. Some subjects will be annotated manually for validation and optimisation purposes. Metrics to be used are likely the *sensitivity* and *dice similarity coefficient*.
Finally, definition of some appropriate paths will be performed using the registered images, the segmented critical structures and the target points, which are selected manually by the surgeon. Implementation will be based on margin maximization and will provide the clinicians with a certain number of proposed paths, all of which will exceed a certain margin from any critical structure. Hereafter, the software leaves the final choice of a clinically or practically optimal path to the surgeon. Some considerations might e.g. be entry through a certain lobe or the fact that the entry point is aesthetically preferred to be behind the hairline.
Based on these three steps, we aim to develop a software tool that may perform the repetitive and time-consuming parts of the path planning process for DBS surgery, leaving the choice and clinical considerations of a final path selection to the surgeon. The final paths created by the software will be compared with the trajectories that were used for the actual DBS procedure, as were defined by the responsible neurosurgeons. Here, we will visually compare the similarity and performance of the chosen trajectories, but also compare the paths quantitatively via an assessment of the margins yielded by both to assess the quality of our method relative to manual path planning.
With this project, we would like to confirm feasibility of (semi-)automated path planning for DBS surgery and pave the way for clinical adoption of such techniques.

Planning-wise, this project will start at the 19th of April, and will end at the 2nd of July. The final deliverables are a paper and a piece of software, the last of which will likely be developed in *Python* and may be distributed open-source via *git*.

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