Towards Digital Atlas- and MRA-guided, Intraoperative MRI-registered Robotic Deep Brain Therapy

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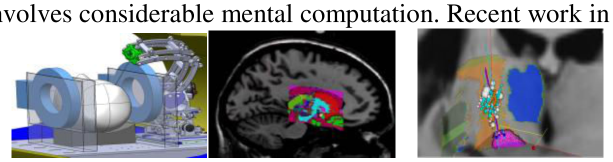
THIS paper presents the initial development of a robot-assisted, intraoperative MRI (ioMRI) guided therapy system that will enhance the workflow of deep brain therapy (DBT) for all of its applications.

I. INTRODUCTION

Deep brain stimulation (DBS) is a technique based on implanted electrodes for treating neurological disorders such as Parkinson's Disease (PD) and epilepsy, while showing promise for psychological disorders like treatment-resistant depression (TRD). Targets vary with indication; the subthalamic nucleus (STN) is commonly used for PD.

Traditional DBS, based a deep brain atlas *in printed form,* places restrictions on the choice of approach and planning involves considerable mental computation. Recent work in computer-guided DBS exploits *one or two* of the following: a digital brain atlas [1]; an electrophysiological (EP) database [2]; a model of venous and arterial structures [3]; and intraoperative MRI (ioMRI) guidance [4]. *To date, no method combines all of these.* This paper presents on-going work in deep brain therapy, spanning both treatment planning and surgical robotics. A CAD representation of the robot, a sagittal view of the digital atlas, and rendered EP data appear in Fig.1.



(a) (b) (c)

Figure 1. Key components (a) MR-compatible stereotactic neurosurgery robot; (b) deep brain atlas overlaid on native substrate [1], and (c) EP database [2] overlaid on 3D tri-planar patient image.

II. METHODS

A. MRI-compatible Robotic DBT Delivery System

In our approach to the application of DBT, the robot will be used to align and insert the delivery cannula along the planned trajectories. The robot will enhance the ability to target multiple points and interactively updated intraoperative MR imaging will ensure that the desired trajectory has been reached, thus eliminating many sources of error inherent in stereotactic procedures. The motivation for the robot is to take advantage of real-time intraoperative imaging combined with efficient nonrigid motion estimation for precise image-guided cannula placement.

B. Efficient Functional and Anatomical Therapy Planning

The key components of the surgical planning include:

- *Digital deep brain atlas*, based on registered slice images of a scanned printed atlas [1], as illustrated in Fig. 1 (b).
- *A probabilistic* EP *database* (fig. 1(c)) [2], summarizing successful target coordinates.
- *Multi-surface Simplex mesh representation* [5], where each mesh has precise control on its resolution.
- *3D Slicer-based planning and navigation software, which features OpenIGTLink to control the robot*. [6] .
- *Vascular modeling* based on blood vessel identification algorithm of pre-operative TOF and SWI data.

III. DISCUSSION

Our philosophy of this work is to make every design choice consistent with the planned integration of intra-operative MRI, in order to provide clinicians with accurate therapy delivery, despite intraoperative brain shift. Thus far, we have designed the system architecture and prototyped the key components in the proposed DBT workflow.

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