Fachhochschule Nordwestschweiz
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Atlas-Based Segmentation Algorithm

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Bachelor-Thesis, Degree Program Biomedical Engineering

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Background

In the field of **deep brain stimulation** (DBS), attempts are being made to understand the clinical effect concerning the **stimulated tissue volume**. **Electric field simulation models** have been developed here at IMT in Linköping, that can predict the volume of stimulated tissue through the electrode. For this simulation, **brain MRI segmentation** into white/grey matter, cerebrospinal fluid (CSF) and blood is done.

Aim

- The goal is to implement an **atlas-based segmentation algorithm**
- The algorithm **saves time** compared to manual segmentation
- With the **same accuracy** as the existing threshold-based segmentation
- The atlas was implemented into a **cyst detection algorithm** and tested
- Cysts influence electric field distribution, therefore, an **automated cyst detection** is important for DBS patients

The Atlas

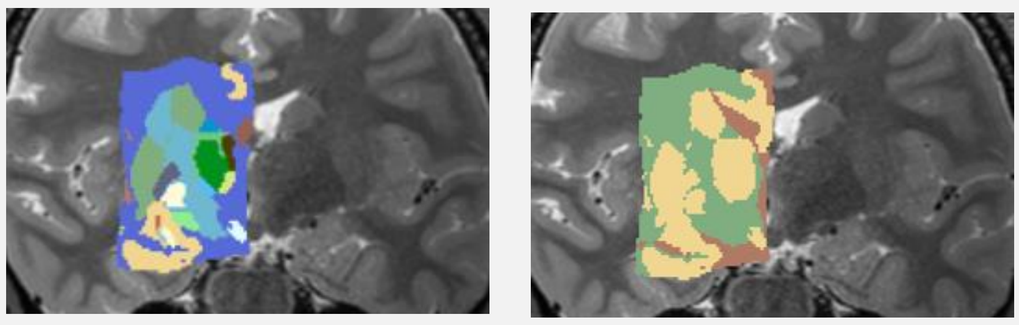

Figure 1: Atlas comparison before and after merged from 123 to 3 labels. After merging, the atlas contained grey matter (yellow), white matter (green) and CSF (red)

Positive Skewness Shift

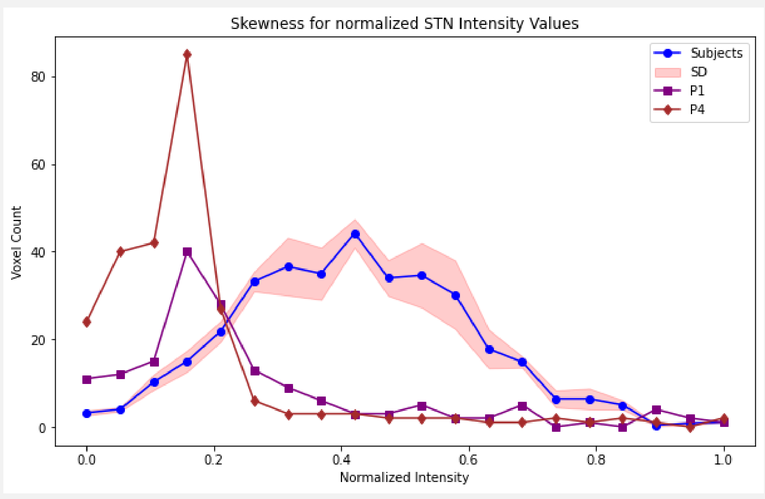

Figure 2: Positive skewness shift for P1 and P4 normalized intensity values in STN compared to healthy subjects. The healthy subjects presented by a standard distribution, while P1 and P2 contained brighter voxel in STN, therefore a longer right tail.

Visual Overlapping

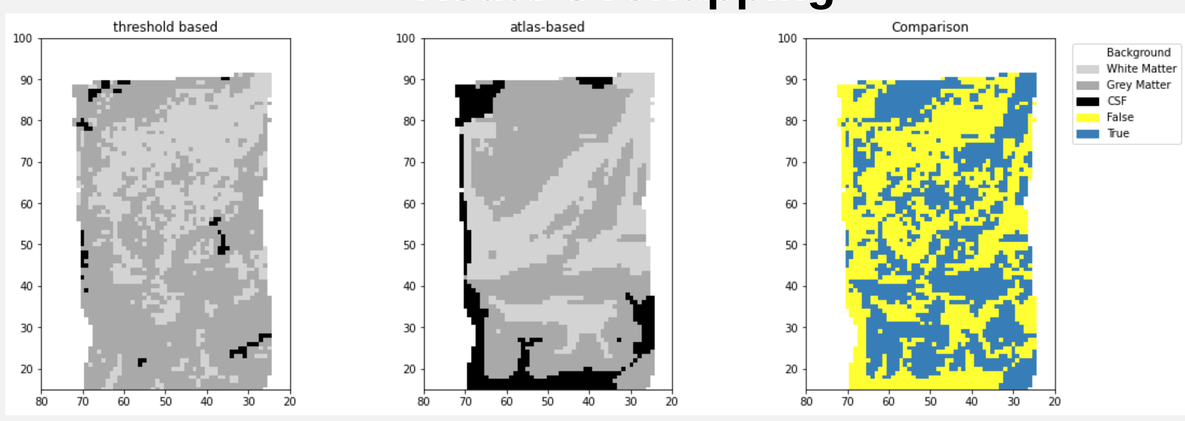

Figure 3: Subject 1001, slide 26. Left the threshold-based segmentation conductivity map, in the middle the atlas-based segmentation conductivity map and on the right the true/false comparison. True positive rate of 46.5 % for this specific slide.

Cyst Detection

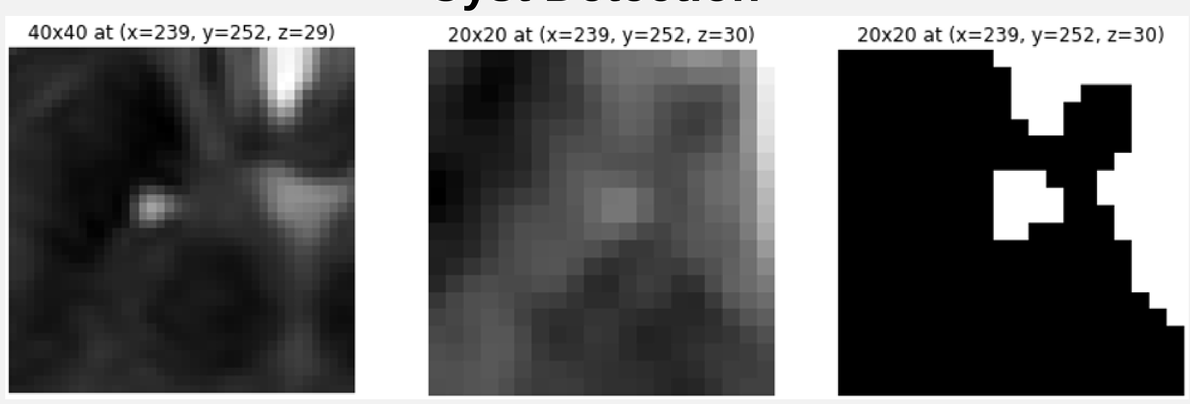

Figure 4: Cutout from potential cyst in P1. Left to right: original MRI at z=29 (the best cyst visibility), cutout from detection [239, 252, 30] and binary cutout from detection.

Methods

The methodology employed involves using multiple tools and datasets for brain segmentation and cyst detection**. The DISTAL 2017 atlas** [1] was used, which includes 123 labels of critical brain structures for DBS (Fig. 1).

Atlas Evaluation:

- **Healthy Subjects**: MRI from the Human Connectome Project (HCP) [2]
- **Software Tools**: Python, MATLAB, 3D Slicer, ELMA, and DBSim
  - **ELMA**: Used for calculating conductivity map from the MRI [3]
  - **DBSim**: Used to simulate the electric field generated by DBS [4]
- **Segmentation Comparison**: Atlas-based segmentation was compared to the threshold-based segmentation
  - **Stimulated volume**: simulation with different background values to evaluate the impact on the electric field distribution
  - **Conductivity map accuracy**: voxel by voxel comparison for DBS regions and the different tissue types
  - **Visual Overlapping**: Visual comparison to explain the accuracy results

Cyst Detection Algorithm:

- **Patient Data**: Two Parkinson disease patient data from Alonso et al. [5]
- **Method**: Thresholding, the regionprops function in Python and limiting the ROI using STN label from the atlas.
- **Threshold Selection**: Based on the distribution of intensity values in STN, considering the positive skewness shift for patients with potential cysts (Fig. 2)
- **Detection Parameters:** Cyst size, distance from STN and intensity Values

Results

- **Stimulated volume increased** to 120.8% ± 1.39% for the atlas-based segmentation compared to the threshold-based method
- Conductivity map **accuracy** was **good for smaller regions** (STN 80.22% ± 4.13%), **worse for larger regions** (CSF 26.15% ± 3.12%) or when **further away from STN area**
- **Pixelation** for the **threshold-based segmentation** (Fig. 3), which is characteristic for MRI
- **Gaussian distribution** in STN intensity value for healthy patient data (Fig. 2)
- **Positive skewness shift** in STN intensity values for DBS patient data with a potential cyst (Fig. 2)
- **Successful cyst detection** for both patient data (Fig. 4)
- Several **false positive detection**
- Detection was **threshold sensitive**
- **Inconsistency** was observed

Conclusion

Atlas-based segmentation was a **viable method** for identifying DBS regions. Cyst detection was **successful**, but there was a notable occurrence of **false positives** and **inconsistency**. Future research should aim at improving the **robustness** of the algorithm and extending its validation to a **larger data set**. Ideas for improvement include **refining the detection** in shape, size, and threshold range parameters.

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References

- [1] https://www.lead-dbs.org/helpsupport/knowledge-base/atlasesresources/distal-atlas/
- [2] https://www.humanconnectome.org/study/hcp-young-adult
- [3] [4] https://liu.se/en/article/ne-downloads
- [5] Alonso et al. “Influence of Virchow-Robin spaces on the electric field distribution in subthalamic nucleus deep brain stimulation.” (2021)