ELECTROPHYSIOLOGICAL SIGNAL PROCESSING FOR INTRAOPERATIVE LOCALIZATION OF SUBTHALAMIC NUCLEUS DURING DEEP BRAIN STIMULATION SURGERY

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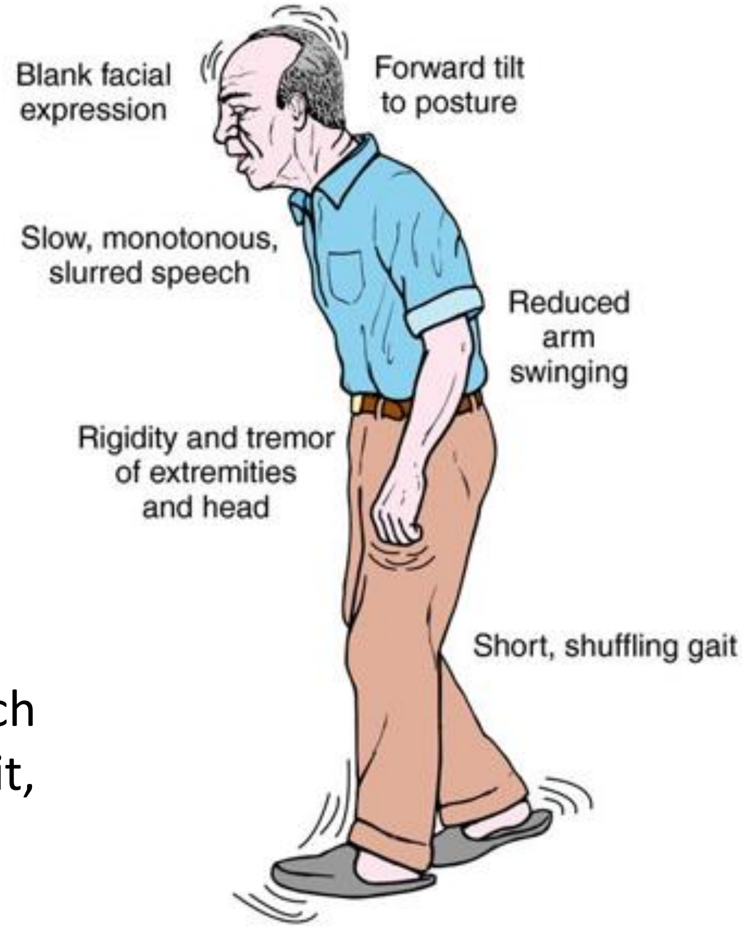
Today's Agenda

- Introduction
- Data Base & Feature Extraction
- Classifiers
- Results
- Conclusion

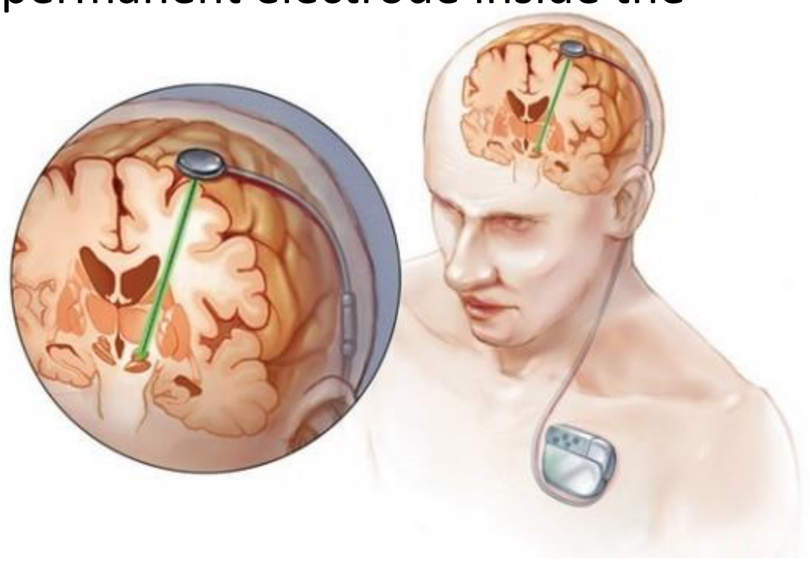
Introduction:

- Parkinson’s disease (PD) is one of the most common neurological disorders.
- It is a progressive disease that affects 1% of people over 60 years of age. Over 100,000 Canadians are living with PD today and approximately 6,600 new cases of PD are diagnosed each year in Canada.
- Motor features of PD result from the death of dopamine neurons in the substantia nigra pars compacta of the Basal Ganglia.
- PD causes motor and non-motor symptoms such as tremor, rigidity, bradykinesia, shuffling of gait, depression and apathy.



Deep Brain Stimulation:

- Oral pharmacotherapy and surgical intervention are both accepted as treatments.
- Deep Brain Stimulation (DBS) surgery is used especially in those that have advanced PD to alleviate some of the symptoms such as tremor.
- DBS surgery involves implantation of a permanent electrode inside the STN to deliver electrical current.

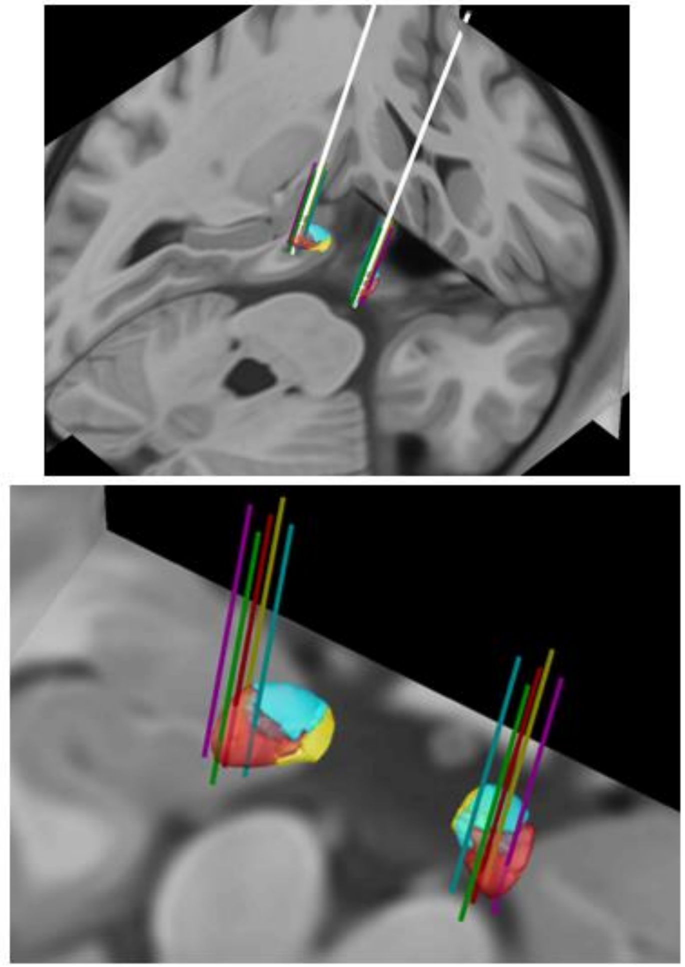


Existing Challenges:

- The surgical outcomes of DBS highly depend on the accuracy of the placement of the electrode inside the STN.
- STN is a very small region (5-7 mm) of the basal ganglia; accurate placement of the stimulating electrode is a challenging task for the surgical team.
- Sub-optimal positioning of DBS electrodes accounts for about 40% of the cases in which inadequate post-operative efficacy of stimulation is reported.
- A common technique to target the STN is through the use of preoperative MR images; however, the exact location of the STN cannot always be identified precisely from MR images.

Micro-Electrode Recording (MER)

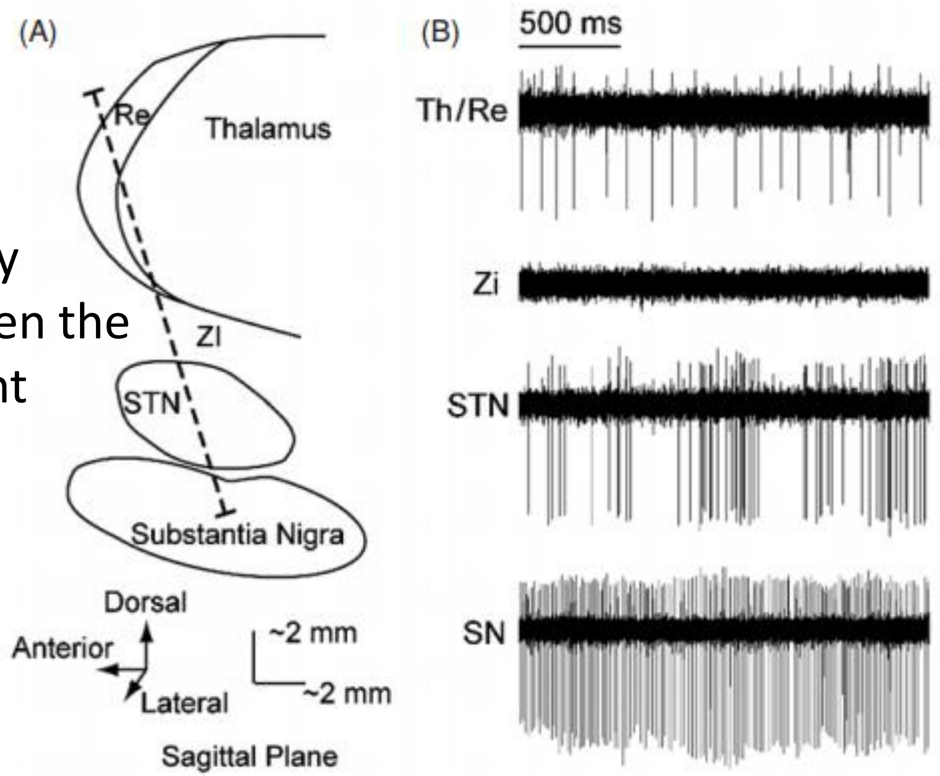
- Intraoperative MERs have been used for localizing the STN; they are observed visually by the surgical team during the operation.
- For most patients, up to five microelectrodes are inserted through a burr hole in the skull on each side of the brain. The microelectrodes record the electrophysiological activities of the neurons along the insertion trajectory.



Inserting the electrodes inside of STN

Deep Brain Stimulation:

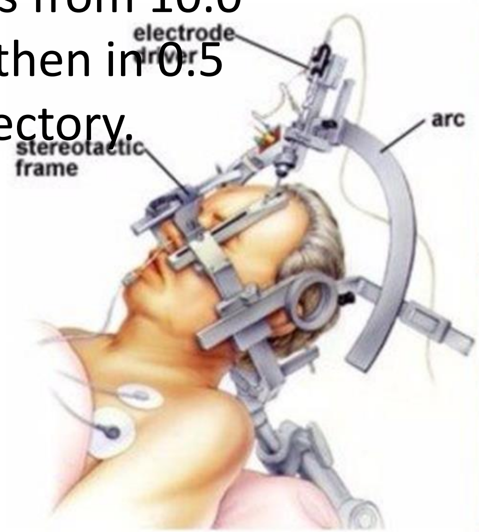
- Electrophysiological activities vary along the insertion trajectory when the electrode passes through different structures of the brain.

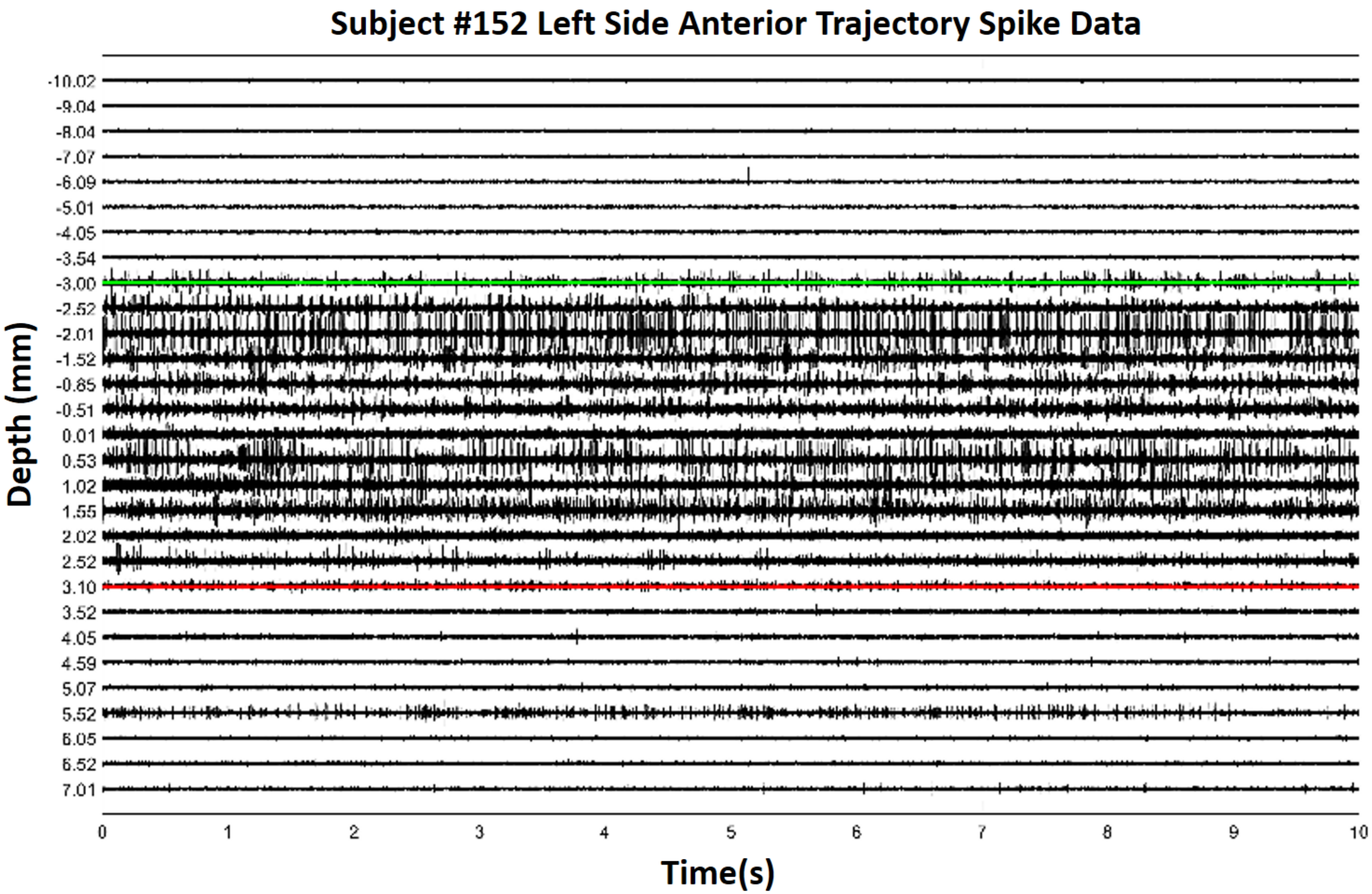


Data Acquisition & Feature Extraction

Data Base:

- For this study, we used MER signals from 100 individuals with PD obtained during their DBS implantation (in total, 713 microelectrode tracks); the data was collected at University Hospital in London, Ontario.
- The data consisted of the motion of the microelectrodes in 1.0 mm increments from 10.0 mm to 5.0 mm above the target, and then in 0.5 mm increments to the end of the trajectory.





Microelectrode Recordings; The green line indicates the dorsal border of the STN and the red line indicates the ventral border of the STN, as decided by the neurosurgeon.

Feature Extraction:

1. Number of spikes per the 10-second interval;
2. Standard deviation of time differences between the spikes of the 10-second interval;
3. Pause index: the ratio between the number of spikes greater than 50 ms to the number of spikes less than 50 ms;
4. Pause ratio: the ratio between the total time of inter spike intervals greater than 50ms to the total time of those less than 50ms;
5. Root Mean Square (RMS) value of the signal amplitude in the 10-second interval;

Feature Extraction:

6. Spiking rate: number of spikes per unit time (one second).
7. Teager Energy, which can be calculated as follows:

$$E = \sum_{i=2}^{N-1} x_i^2 - x_{i-1}x_{i+1}$$

where, $x_i \in X = \{x_1, x_2 ... x_n\}$ and N is the number of samples in each signal;
8. Zero crossing: the number of zero crossings in each 10-second interval;
9. Curve length: the sum of consecutive distances between points in the 10-second interval, as calculated below:
10. Threshold:

$$\gamma = \frac{3}{N-1}\sqrt{\sum_{i=1}^{N}(x_i - \bar{X})}$$

Feature Extraction:

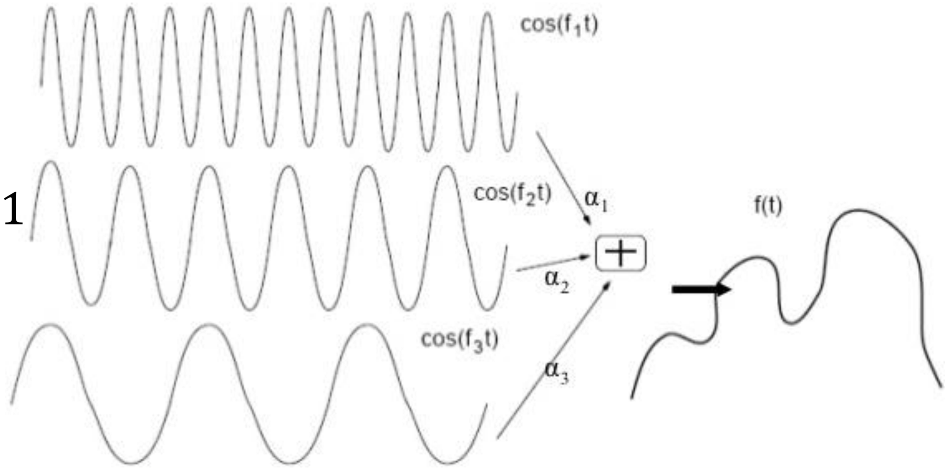
- Conventional Post-Operative Features:

  Number of Spikes, Pause Index, Pause Ratio, Root Mean Square (RMS), Spiking Rate, Teager Energy, Zero Crossings, Curve Length, and Threshold.

- Fast Fourier Transformation Features:

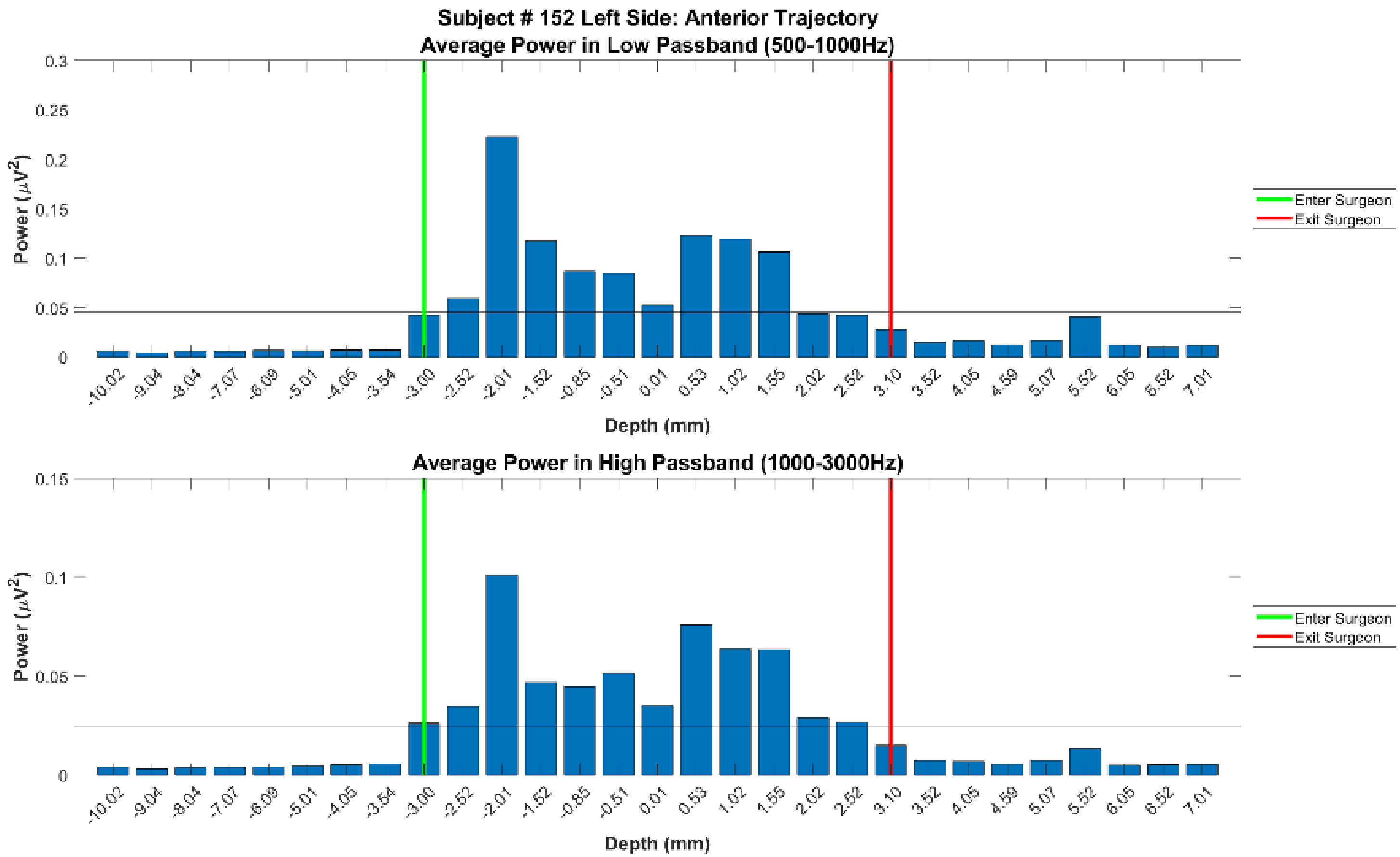
  FFT-based feature space can provide valuable information about the location of the microelectrodes since they encode the frequency context of neural activities.

$$F(u) = \frac{1}{N}\sum_{x=0}^{N-1} f(x) e^{\frac{-j2\pi ux}{N}}, u = 0,1,\dots,N-1$$



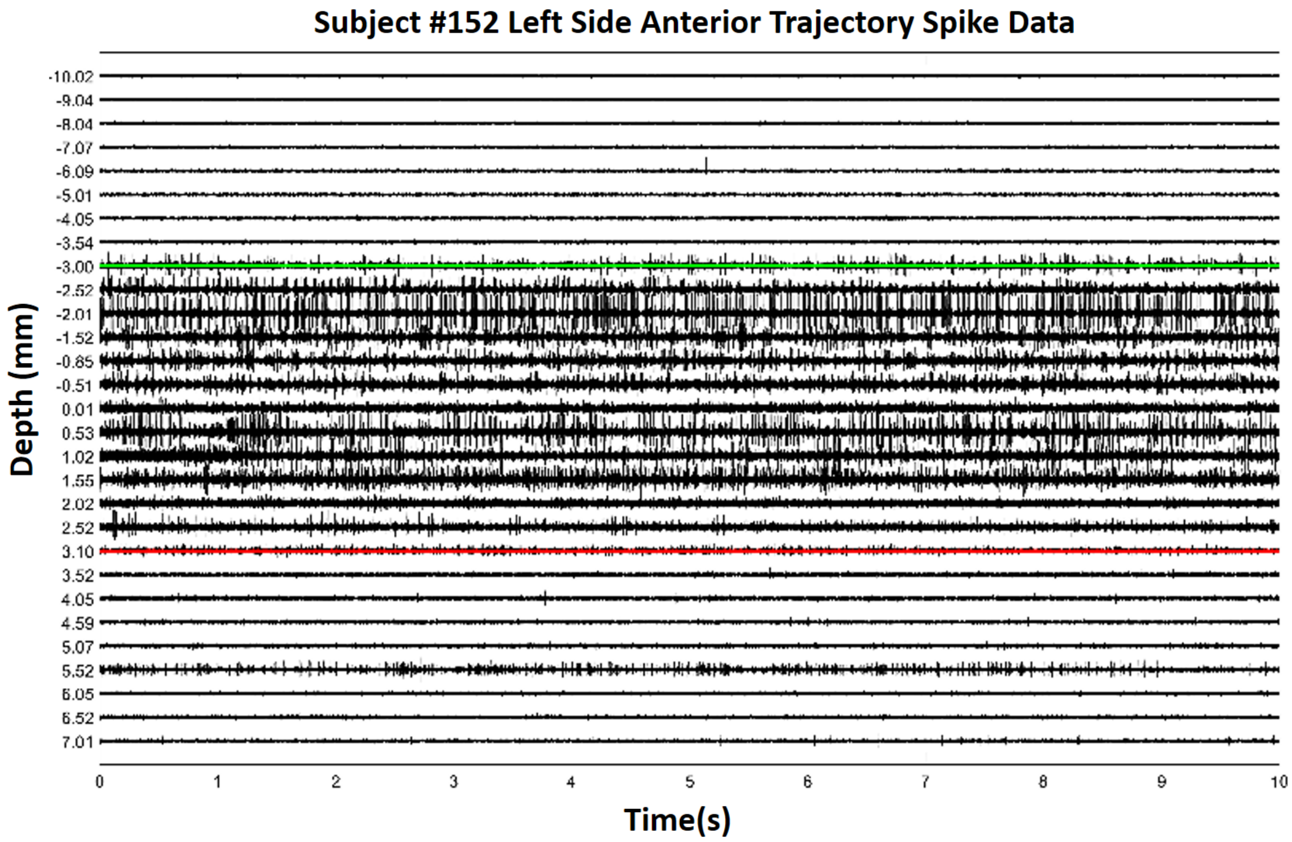
Feature Extraction

When the microelectrode is within the STN, there is a shift in frequency domain of the MER signal.



Supervised Classifiers: Logistic Regression Support Vector Machine

Labels for the Data:

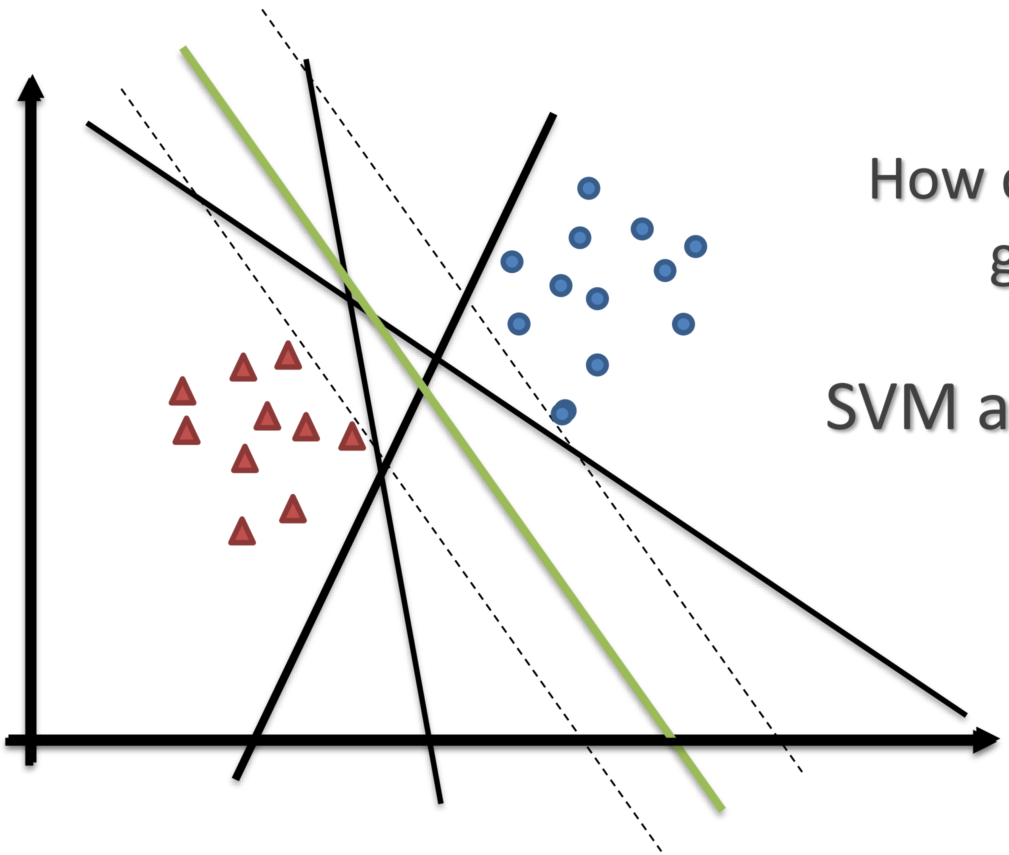


Labeled as outside of STN ⇨ 0

Labeled as inside of STN ⇨ 1

Labeled as outside of STN ⇨ 0

Support Vector Machine:

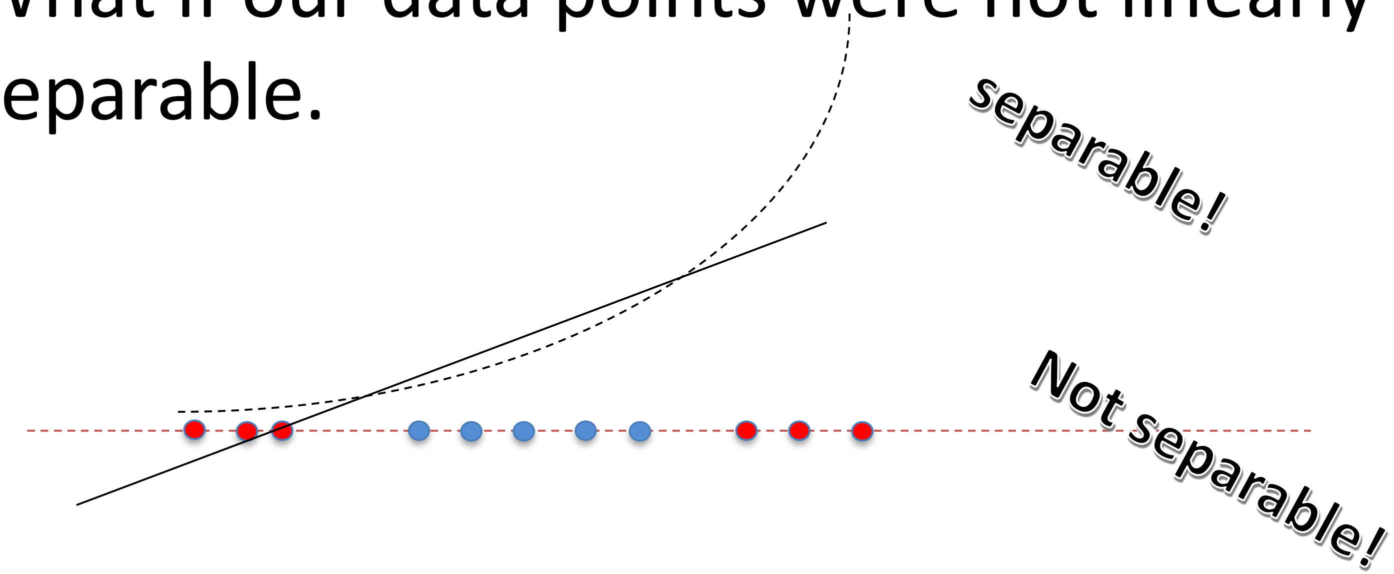


How do we separate these two groups with one line?

SVM algorithm finds this line!

Kernels:

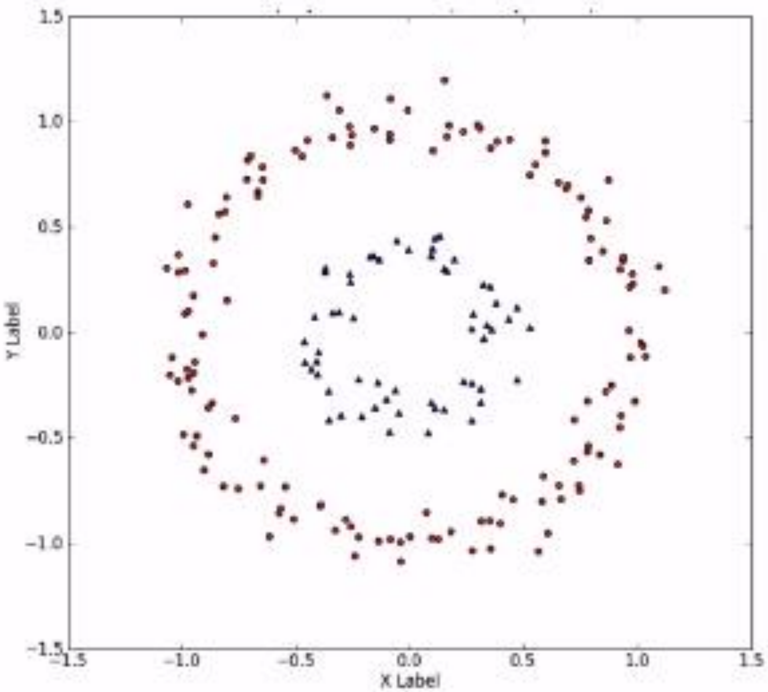
- What if our data points were not linearly separable.

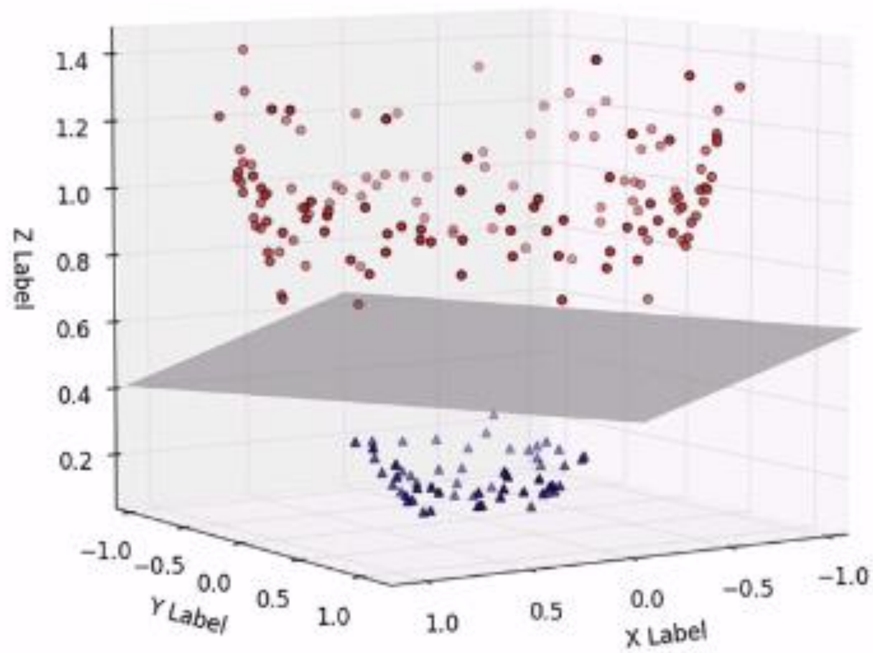


Types of Kernels:

Linear ,Quadratic and Cubic

Kernels:





Results with Supervised Algorithms

Train and Test Data:

labeled data

Training	Validation	Test
≈60%	≈20%	≈20%
train tunable parameters **w**	train other parameters, or to select classifier	use **only** to assess final performance
427 tracks	142 tracks	142 tracks

Results:

Table 1. Accuracy of Classifiers for Localizing STN

Features\classifiers	LR	SVM(Linear Kernel)	SVM(Quadratic Kernel)	SVM(Cubic Kernel)
The 10 extracted features used in [11]	71%	70%	72%	76%
FFT coefficients	81%	80%	82%	85%

Conclusion & Future Work

Conclusion:

- This study presented a new technique that can be used to assist the neurosurgeon during the DBS procedure by providing an objective assessment of the STN location.

- Based on the conducted study, a combination of FFT-based features and a Cubic kernel SVM algorithm was suggested as a high performance approach that can localize STN during surgery.

Reference:

[1] M. Khosravi, R.V. Patel, “Electrophysiological Signal Processing for Online Localization of Subthalamic Nucleus during Deep Brain Stimulation Surgery ”, IEEE Global Conference on Signal and Information Processing, USA, 2018.

[2] S. Wong, G. Baltuch, J. Jaggi, and S. Danish, “Functional localization and visualization of the subthalamic nucleus from microelectrode recordings acquired during DBS surgery with unsupervised machine learning,” *Journal of Neural Engineering*, vol. 6, no. 2, p. 026006, 2009.

[3] P. Guillen, F. Martinez-de Pison, R. Sanchez, M. Argaez, and L. Velazquez, “Characterization of subcortical structures during deep brain stimulation utilizing support vector machines,” in *Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE*, 2011, pp. 7949–7952.

[4] V. Rajpurohit, S. F. Danish, E. L. Hargreaves, and S. Wong, “Optimizing computational feature sets for subthalamic nucleus localization in dbs surgery with feature selection,” *Clinical Neurophysiology*, vol. 126, no. 5, pp. 975–982, 2015.

A recent published review paper on previous works:

Table 1
Summary of papers in chronological order.

First author	Moran	Zaidel	Wong	Cagnan	Chaovalitwongse	Cardona	Ciecierski	Rajpurohit	Schiaffino	Valsky
Year	2006	2009	2009	2011	2011	2012	2014	2015	2016	2016
Patients, n	27	21	27	48	16	nr	nr	26	8	81
Data analyzed										
Recordings, n	nr	nr		6064	nr	190	16,000	nr	1760	4526
Trajectories, n	36	56	43	258	nr	nr	nr	56	nr	131
Length, s	5	>5	4	nr	4	nr	nr	4	1	>4.5
Spike independent features										
Estimated distance to target (EDT)	✓	✓								✓
Basal amplitude				✓			✓		✓	
Signal kurtosis									✓	
Curve length (CL)			✓		✓			✓	✓	
Threshold			✓		✓				✓	
Peaks			✓		✓			✓	✓	
Average nonlinear energy (ANE)			✓		✓				✓	
Zero crossings			✓		✓			✓	✓	
Teager energy								✓		
Normalized root mean square (NRMS)	✓	✓	✓		✓			✓		✓
Noise mode								✓		
Power spectral density (PSD)		✓		✓		✓	✓			✓[a]
Spike dependent features										
Modified burst index (MBI)			✓		✓		✓	✓	✓	
Pause index (PI) and Pause ratio (PR)			✓		✓			✓	✓	
Compound firing rate (CFS)			✓	✓	✓		✓	✓	✓	
Mean spike amplitude differential			✓		✓			✓	✓	
Standard deviation of interspike intervals (ISI rms)			✓		✓	✓		✓	✓	
Mean spike trigger frequency									✓	
Spike fraction			✓		✓			✓		
Machine learning models										
Bayesian	✓				✓[b]	✓[c]	✓	✓[d]		
Decision tree					✓[e]		✓[f]			
Support vector machine								✓		✓
K-nearest neighbor			✓[g]		✓[h]			✓[i]	✓[g]	
Logistic regression								✓		
Hidden Markov model		✓[j]						✓		✓
Supervised learning	✓	✓	✓		✓	✓	✓	✓	✓	✓
Online						✓	✓			
Sites										
Thalamus								nr	✓	
Zona incerta					✓			nr		
Subthalamic nucleus entry	✓	✓	✓	✓	✓	✓	✓	nr	✓	
Subthalamic nucleus exit	✓	✓	✓	✓	✓			nr		✓
Substantia nigria					✓			nr	✓	

The most recent and the state-of-the-art work:

Published in final edited form as:
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Stop! Border Ahead: Automatic detection of subthalamic exit during deep brain stimulation surgery

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Abstract

Background—Microelectrode recordings along pre-planned trajectories are often used for accurate definition of the subthalamic nucleus (STN) borders during deep brain stimulation (DBS) surgery for Parkinson's disease. Usually, the demarcation of the STN borders is detected manually by a neurophysiologist. The exact detection of the borders is difficult and especially detecting the transition between the STN and the substantia nigra pars reticulata. Consequently, demarcation may be inaccurate, leading to sub-optimal location of the DBS lead and inadequate clinical outcomes.

- Only detect the ventral border
- Uses Normalized RMS
- Results based on 131 Microelectrode

Thank you for listening

Any Questions?

For more information, please contact:
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