Dynamical State Change Detection and Classification in EEG data from Healthy Individuals and Parkinson's Patients

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Introduction

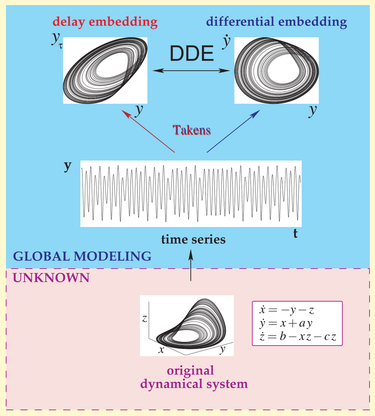
Problem

Much of how the brain plans, initiates and executes coordinated movements is poorly understood. Parkinson's Disease provides a naturally occurring window into the modulation of cortical activity by deep brain structures. The dominant symptoms of Parkinson's Disease, e.g. bradykinesia, masked facies and shuffling gate, indicate that Parkinsonian patients may have significant impairment when switching between pre-motor, motor, and post-motor states.

Hypothesis

Features obtained using delay differential equations (DDEs) will provide the information necessary to discriminate between pre-motor, motor and post-motor states in healthy control and Parkinson on/off-medication subjects. Features providing the best classification can be utilized to show states changes with respect to time in densely sampled EEG data based on singular value decomposition across features. State changes observed in the singular values will occur at a later time point in Parkinsonian patients than in healthy controls. Classification at the single electrode level will further inform on network level differences between motor states.

DDEs



DDE analysis is done in the time domain and not in the spectral domain!

$$\dot{x}(t) = f(a, x(t), x(t-\tau_1), x(t-\tau_2), \ldots)$$

linear terms: dominant time scales
non-linear terms: frequency couplings $\Rightarrow$ coefficients a_k and least square error as features

Why DDEs?

- Computationally fast
- DDEs are built solely from data and output is dictated by changes in the underlying dynamics of the system
- Used for both short and sparse data

Connection to Frequency

Generic non-uniform embedding
$\Updownarrow$ *DDE*
Combination of frequency analysis with higher order statistics

Structure Selection

Training

$$\mathbf{A}_{i,j} = (a, \rho)_{i,j}$$

$$\mathbf{A}_i \cdot \mathbf{W}_i = \mathbf{S}_i = \begin{cases} 1 & i \in State\ 1 \\ -1 & i \in State\ 2 \end{cases}$$

Testing

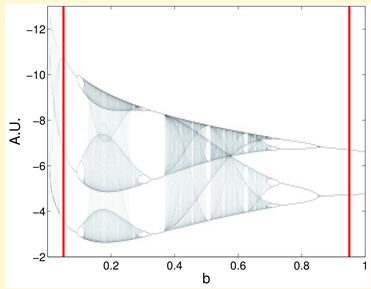
$$\mathbf{T}_{k,j} \cdot \mathbf{W}_j = d_k$$

Singular Values

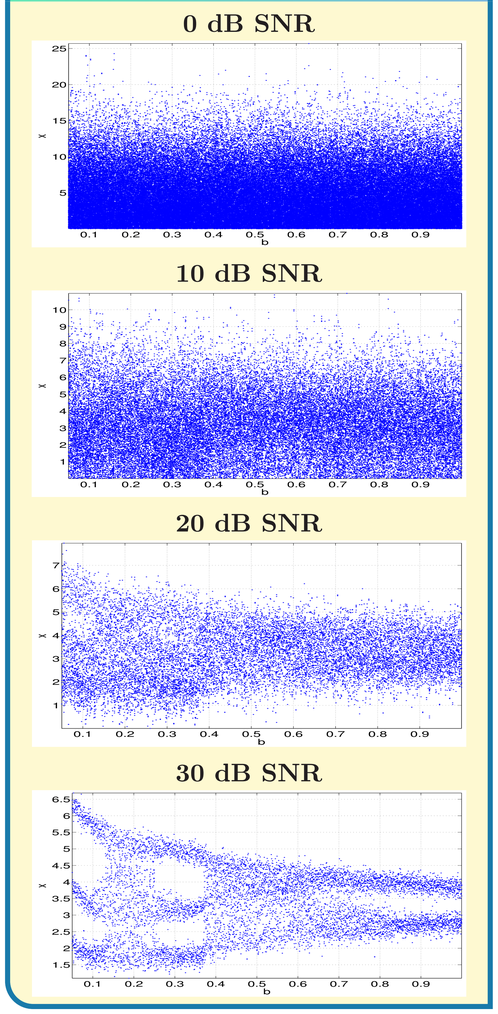
- Select top 100 model-delay pairs based on classification performance
- Densely sample time series and acquire features for top 100 model-delay pairs
- Perform singular value decomposition across feature set for each time point

Rössler System

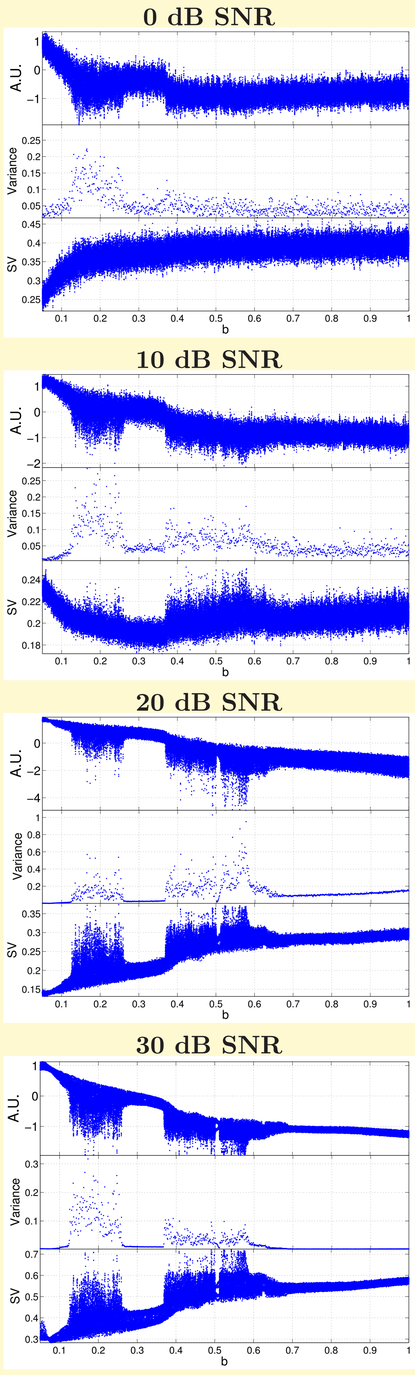
$$\begin{aligned} \dot{x} &= -y - z \\ \dot{y} &= x + a\,y \\ \dot{z} &= b - c\,z + x\,z \end{aligned}$$



Poincare Section



DDE-SV Method



Experimental Setup

Subjects

- 6 healthy adults
- 6 patients with PD (ON and OFF medications)

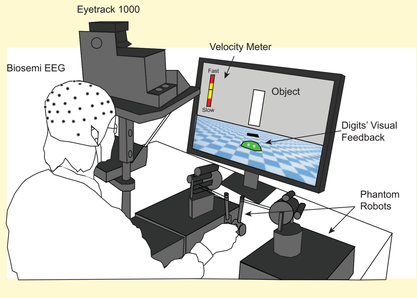
Task

- Reached for and grasped virtual object (n=128)

Experimental Recordings

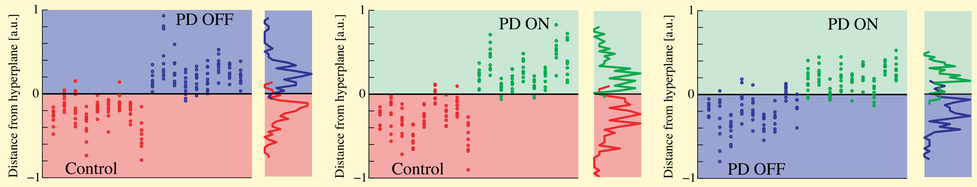
- Biosemi EEG 64-channel data
- Eyelink 1000 eye-tracking data
- Phantom robot kinematic data

Setup:

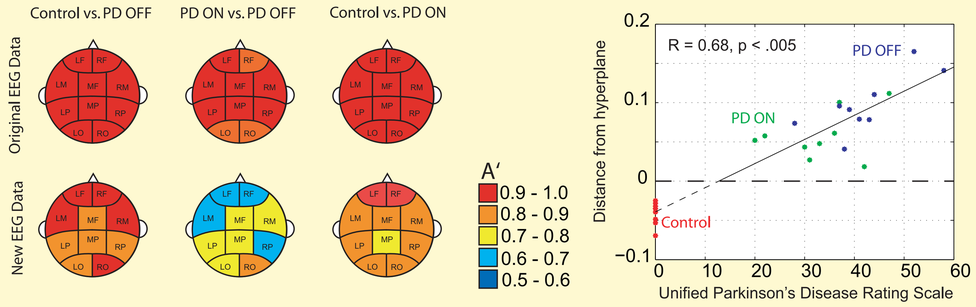


Preliminary Results - Classifying Subjects by Class

DDE model output: Distance from the hyperplane in classification of controls vs. PD patients off medication, controls vs. PD patients on medication, and PD patients on vs. off medication with 1-s resting state EEG data.

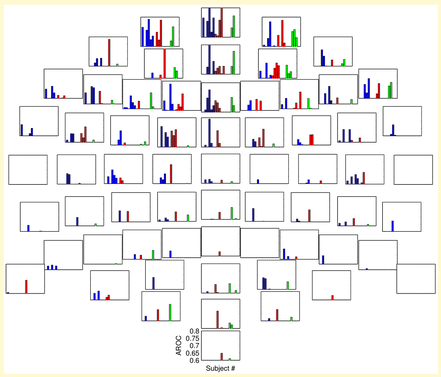


Classification performance of three different classifications using A' (Area under the receiver-operating characteristic curve):

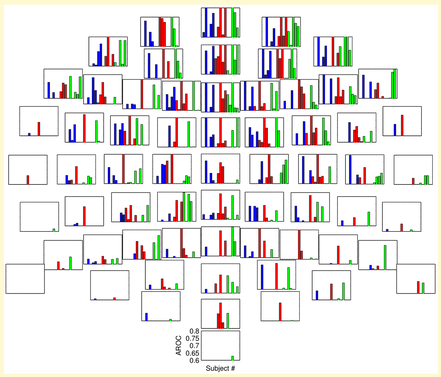


Intra-trial Electrode Based Classification

Tone

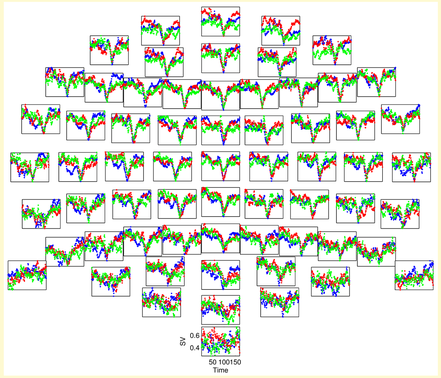


Grasp

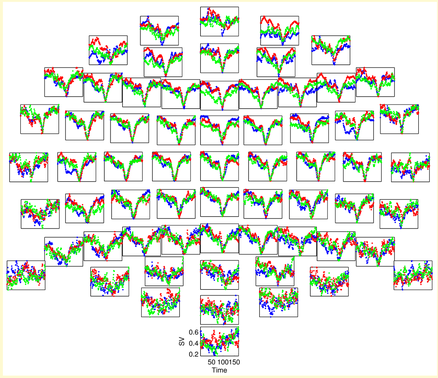


DDE Singular Values

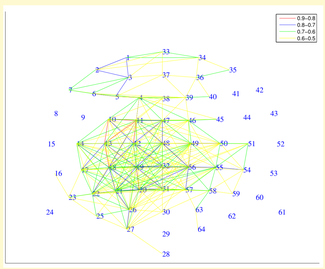
Tone



Grasp



Network Analysis



Conclusion

- DDE features are able to classify motor states at the electrode level
- Singular Value Decomposition on densely sampled DDE feature space shows global changes corresponding to Tone and Grasp
- Network analysis of electrode classification provides a unique perspective of electrode networks that similarly classify motor states.