A SPATIO-TEMPORAL FILTERING APPROACH TO EPILEPTIC FOCUS LOCALIZATION

Carnegie Mellon University

Electrical & Computer ENGINEERING

Haewon Jeong

Department of Electrical and Computer Engineering

Introduction

Motivation

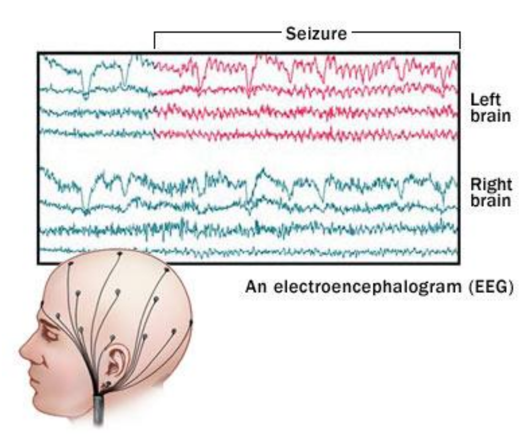
- ~1% of Americans suffer from epilepsy; ~20% of these cases can only be treated surgically
- Accuracy of source localization is an impediment to using advanced techniques to localize the epileptic focus for surgical removal
- State-of-the-art source-localization algorithms rely only on spatial information
- Using both spatial and temporal information can yield higher localization accuracies

Challenges

- Formulating a novel spatio-temporal filtering algorithm for source localization that is tractable

Goal

- Implement a spatio-temporal beamforming algorithm
- Compare performance against a spatial-only beamforming technique



LCMV Beamformer

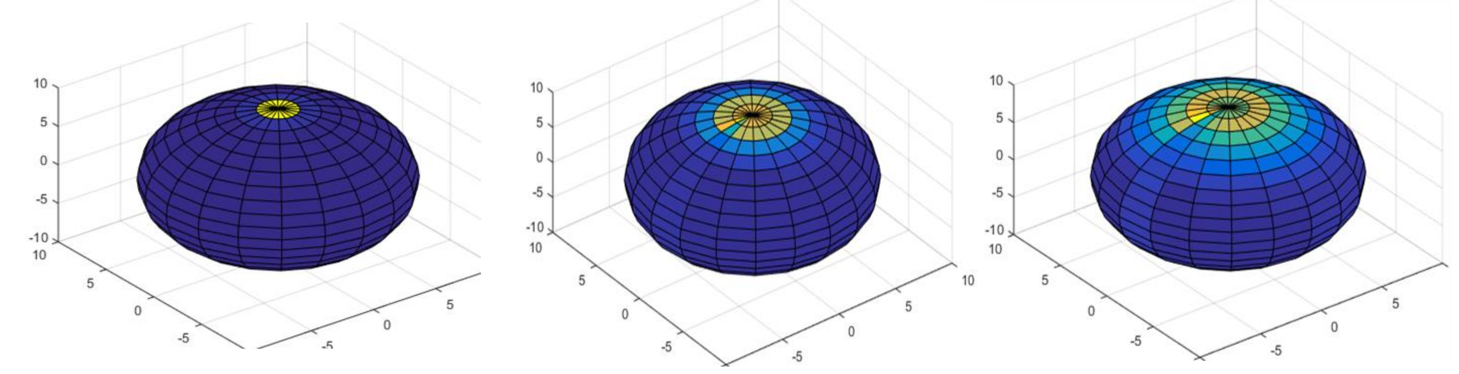
Linearly Constrained Minimum Variance (LCMV) Beamformer

(IDEA) Hypothesize that a source exists at $\mathbf{q_0}$. Find a spatio-temporal filter **W** that captures the expected activity originating from $\mathbf{q_0}$ in space-time.

- **N** sensors, **L** possible dipole locations
- $\mathbf{x = \Sigma_{i=1..L} H(q_i)*m(q_i)}$: N by 1 vector of measurements
- $\mathbf{H(q_i)}$: N by 3 forward matrix for the dipole at q_i,
- $\mathbf{m(q_i)}$: dipole moment at q_i (3 by 1 vector)
- $\mathbf{y = W(q_0)^T x}$: filtered signal
- $\mathbf{W(q_0)}$: N by 3 spatial filter matrix centered at q_0
- **We want to solve:** $\mathbf{W(q_0) = \min_W tr\, Cov(y)}$ subject to $\mathbf{W^T H(q0) = I}$

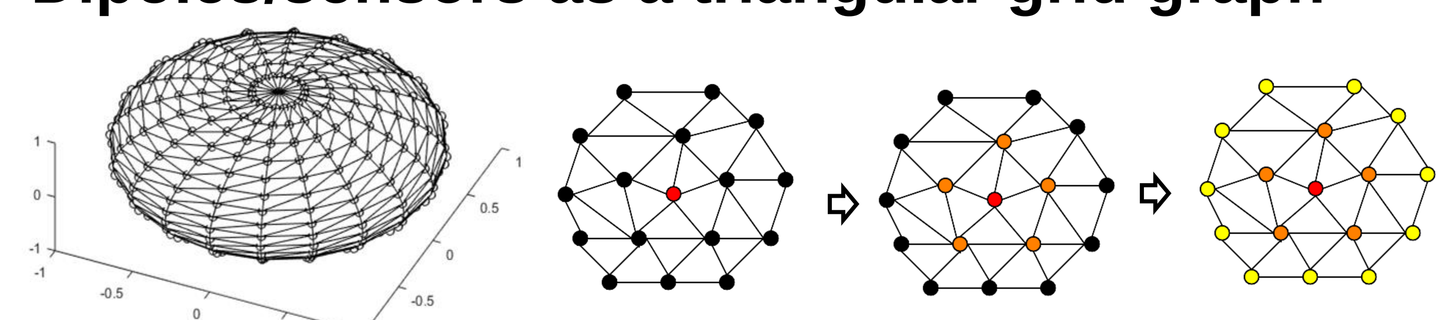
Modelling of Seizure Propagation

Seizure activity expands its region over time



t = 1 t = 2 t = 3

Dipoles/sensors as a triangular grid graph



Grid of sensors on a sphere

t = 1 t = 2 t = 3

Model as a graph

Equation for propagation

$$\underline{\mathbf{m}}_t = (a\mathbf{I} + b\mathbf{A})\, \underline{\mathbf{m}}_{t-1}$$

$\mathbf{m_t}$: measurement at time t

a : constant for preserving the previous value

b : constant for the propagation from the neighbors

A : adjacency matrix

Spatio-Temporal Filtering

- **T :** time window of epileptic seizure
- **H(q):** spatio-temporal forward matrix for dipole source at q (NT by 1)

$$\mathbf{H(q)} = \begin{pmatrix} \mathbf{H(q)_0} \\ \mathbf{(aI + bA)\, H(q)_0} \\ \mathbf{(aI + bA)^2 H(q)_0} \\ \mathbf{\cdots} \\ \mathbf{(aI + bA)^{T-1} H(q)_0} \end{pmatrix}$$

- $\mathbf{x = \Sigma H(q)*m(q)}$ **:** measurements across all sensors over time (NT by 1)
- **W(q):** spatio-temporal filter matrix for dipole source at q (NT by 1)
- $\mathbf{y = W(q)^T * x}$ **:** estimated dipole moment magnitude at q
- **We want to solve:** $\mathbf{W(q) = \min_W Var(y)}$ subject to $\mathbf{W^T H(q) = 1}$

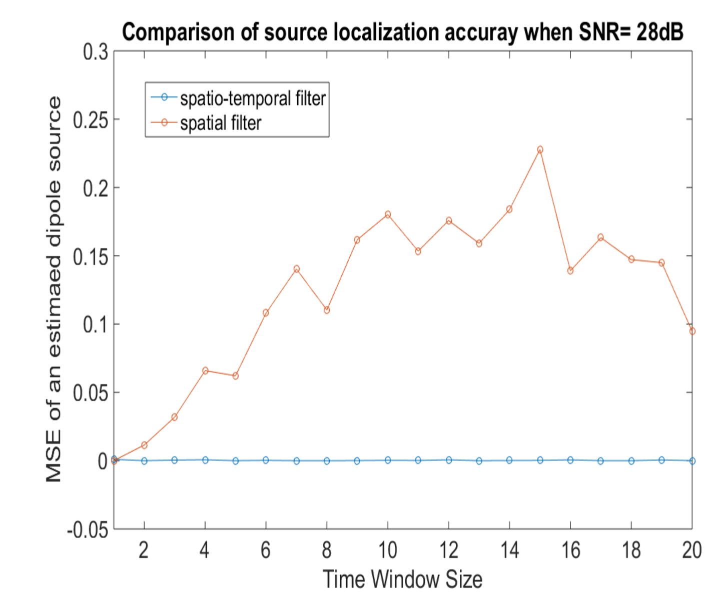
Results

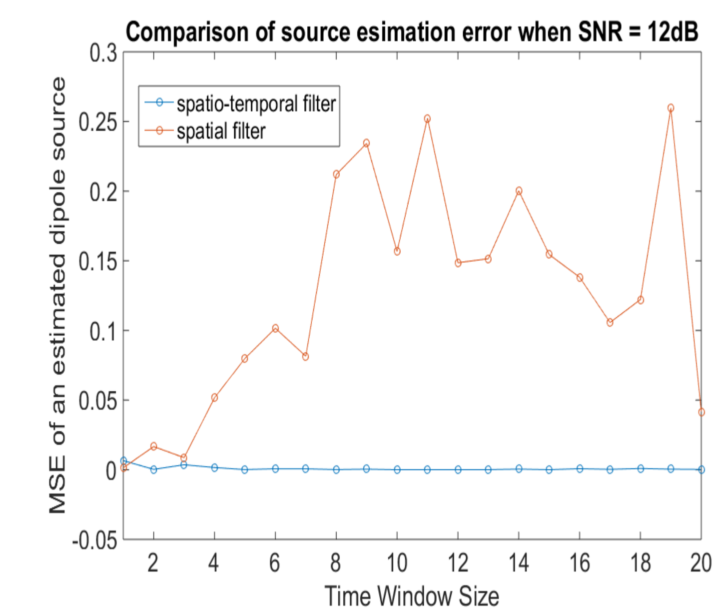
Solution

By deriving the dual problem and solving the KKT conditions, we get:

$$\mathbf{W(q) = [H^T(q) C^{-1}(x) H(q)]^{-1} H^T(q)\, C^{-1}(x)}$$

Localization Accuracy comparison





Future Works

Test with real EEG data

The results here are obtained from clean, simulated data. There would be more issues to be addressed to deal with the real seizure EEG data

Jointly optimizing a, b, W :

The method assumed knowledge of the temporal dynamics of the spread of activity. What if we don't have this information? Can we still apply the same strategy?

- **We want to solve:** $\mathbf{\min_{W,a,b} Var(y)}$ subject to $\mathbf{W^T H(q) = 1}$

References

- *Oostenveld, R., Fries, P., Maris, E., Schoffelen, JM (2011) FieldTrip: Open Source Software for Advanced Analysis of MEG, EEG, and Invasive Electrophysiological Data.*
- *B. D. Van Veen, W. Van Drongelen, M. Yuchtman, and A. Suzuki (1997) Localization of brain electrical activity via linearly constrained minimum variance spatial filtering.*
- *S. Baillet, J. C. Mosher, and R. M. Leahy. (2001) Electromagnetic brain mapping.*