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The Renormalization Method: A Real-time EEG Source Localization Technique

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I. CONTEXT

- Electroencephalography (EEG), a widely used brain imaging technique:
  - Noninvasive, easy to use, inexpensive, very high temporal resolution (ms).
  - Poor spatial resolution (volume conduction, poor SNR).

- EEG scalp potentials can be input into the ill-posed brain source imaging inverse problem: Localizing the electrical current sources in the brain that generate these potentials.

- Our idea: Adapt an approach initially developed to solve a source term estimation problem for atmospheric dispersion of NRBC substances, called “Renormalization” (TRL 5-6), in real time.

- Using anatomically faithful high-resolution 3D head models (FEM), our approach can provide valuable insights for neurophysiological & cognitive monitoring.

II. OBJECTIVES

- Can the Renormalization method bring valuable additional information as compared to other existing source imaging techniques (Minimum Norm, LORETA, MUSIC, Beamformers, …)?

- Evaluate the complementarity between our source localization technique and classical signal processing pipelines (CSD, time-frequency analysis, Machine Learning, …) to improve real-time interpretation of EEG signals.

  => To open new perspectives in the field of Brain-Computer Interfaces (BCIs) and to contribute to a better understanding of cognitive functions to improve the care of brain-injured patients (post-TBI rehabilitation assessment, …).

- Implement and evaluate both a BCI prototype and a new post-TBI rehabilitation assessment pipeline that integrate our method.

III. METHOD

- The workflow:
  1) Compute the lead field matrix A from a sensor point of view.
  2) Generate the visibility matrix W, corresponding to a tensor field, via a “3D renormalization” process.
  3) Compute the estimated source s at each time step by applying the inverse operator G to the measurement vector μ.

- The source estimation enables:
  1. Accurate real-time mapping of electrical brain activity.
  2. Characterization (position, orientation & intensity) of single punctual or distributed sources.

- Improved neurophysiological & cognitive monitoring
  - EEG acquisition
  - Visual feedback
  - Electrodes 3D config.
  - Lead fields + Visibility computation
  - Forward model: As = μ
  - Inverse model: s = Gμ
  - Renormalization
  - Head model (FEM)

- More reliable Brain-Computer Interfaces (BCIs)
  - Exoskeletons, prostheses, …
  - Drones (UAVs, …)
  - VR, software …

IV. CONCLUSION & OUTLOOK

- Possible applications:
  - Improved neurophysiological & cognitive monitoring
  - More reliable Brain-Computer Interfaces (BCIs)
  - Neurophysiological monitoring in real time
  - Accurate localization of epileptogenic foci
  - Cognitive states monitoring
  - Surgical efficacy improvement
  - Patient-tailored treatment

- Work remaining:
  - Compare our Renormalization method’s outputs with other existing source imaging techniques results, based on the EEG recordings of a 20-subject dataset.
  - Implement the real-time part and display the 3D source vectors at each time step.
  - Explore the potential links between our source localization method and Connectivity.
  - Implement and evaluate a BCI prototype as well as a post-TBI rehabilitation assessment pipeline.