A Programmable Laboratory Testbed in Support of Evaluation of Functional Brain Activation

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Introduction

- New infrared spectroscopy (NIRS) and electroencephalography (EEG) imaging setup
- Complementary existing technologies with desirable attributes:
  - Inherently compact form factor
  - Sensitive to hemodynamic (NIRS) and bioelectrical (EEG) phenomena associated with neural activity
- BRIEF: experimental phantom-based systems, analogous to those routinely used to evaluate electronics design methods, currently are unavailable
- Important for the development of functional imaging applications based on NIRS or EEG, or both in combination
- Would be useful to quantitatively assess the accuracy of derived functional information
- To address the need, we have undertaken a technology integration effort with the following aims:
  - Ability to initiate and recover complex macroscopic behaviors that, in general, are not directly observable
  - Implement the desired behavior in a longitudinally stable, anthropomorphic head form that supports translation from laboratory-based to subject-based studies
  - The testbed is addressed by manufacturing programmable dynamic phantoms for hemodynamic and bioelectrical studies
  - Device has an anthropomorphic form similar to one we reported several years ago (1), but:
    - Important addition: headform is mechanically adjustable, allowing for space that is established against biological degradation
  - Directly model bioelectric source elements—electrochromic cells (ECC) and electric dipoles—so that precisely controlled electronically.
  - Interpretation of the voltage across ECC leads changes in opacity, in a way mimicking time-varying blood volume or oxygen saturation.
  - The dipole can be used similarly to model time-varying NIRS sources.
- The second objective is accomplished by employing the same sensing device, header, and analytic methods used in human or animal studies to explore the programmatic validating environment, or testbed.

Testbed Components

Anatomomorphic Dynamic Phantom

- A phantoms headform was introduced by a ‘brain’ into the phantom (Fig. 1(A)).
- Composed of a hydrogel-based biocompatible with saline added to mimic impedance typical of head tissue.
- Commonly available labs are included to inhibit bacterial and mold growth
- TGO, and Inductive are added to the biocompatible physically plausible optical coefficients
- The embedded source grid includes two different types of signal-generation arrangements (Fig. 2):
  - An ECC, dipole and loading-light
    - Loading-light permits manipulation of energy signals and accompanying neural signals.
  - All are within an integrated assembly with dimensions of 8 cm
- Displayed outputs:
  - Measured biotissue sources that are controllable.
- By varying the voltage across an ECC, brain activity signals are generated.
  - Ranges from a general level to macroscopic level functions that mimic hemodynamic responses to light
  - All electronic elements are independently controllable.

Neurophotonics Data Analysis and Display Environment

- Neurophotonics data analysis and display environment is based on knowledge of individual subject boundary conditions.
- For cases with individualized structural information in not available, an alternative solution is to introduce a selected field (Fig. 1(C)):
  - Has generated a series of overlapping regions that support specification of arbitrary sensor arrangements
- A montage of standard EEG electrode locations is provided to guide assignment of NIRS epicenter points.
- Once a sensor arrangement is specified, determination of the associated imaging operators is immediately available.

Anti-Arrhythmia Mapping

- Ideally, NIRS or EEG inversion-problem computations is based on knowledge of individual subject boundary conditions.
- For cases where individualized structural information is not available, an alternative solution is to introduce a selected field (Fig. 1(C)):
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Brain Computer Interface

- Model brain activity signals that are detectable by EEG but not by NIRS measurements.
- EEG signal is recorded from a grid of lead frontal area.
- Any single lead allows mapping underlying structural information for the need in an individual subject and a group-averaged brain structure (to minimize effects of individual variability)
- Experimental data from a macaque-head phantom, in combination with the Fig. 4 of atlas, shows that the model predicts high spatial and temporal accuracy in recovered images.

Conclusions

- The time-varying voltage signals shown in Fig. 7 were used to drive three ECCs of a phantom similar to the one in Fig. 1(A)
- The advised ECCs are embedded in tissues corresponding to the right frontal (F3), temporal (T8) and occipital (O1) surfaces
- The driving functions were derived by sub-band filtering a mathematical model (2) by the set transcranial response (input stimulus), in this case the cortical region that intersect with each other in an effective connectivity network (Fig. 8, Network 1)
- The approach of (1) has been extended by introducing a “brain” into the phantom (Fig. 1(A)).