A Framework for Synthetic fNIRS Data Generation

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Introduction

- Synthetic data generation is critical for validating fNIRS models in situations where ground truth is inaccessible. It strikes a balance between the simplicity of forward modeling and adherence to specific constraints. We introduce a versatile framework that uses the Tak and Friston's bilinear model for fNIRS data, incorporating both physiological and instrumental noise. This system facilitates the creation of both synthetic and semisynthetic datasets, advancing algorithm validation and pipeline development.

Main contributions

Semisynthetic Noise Generation: *Utilizes precompiled fNIRS resting-state data, with the option to add custom datasets.*

Flexible Noise Generation: *Incorporates physiological, motion artifacts, and instrumental noise to simulate realistic conditions.*

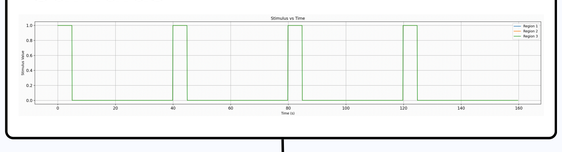
Synthetic Noise Generation: *Includes the options of heart rate, breathing, vasomotion, and customizable colored noise models to simulate disturbances.*

User-Friendly Interface: *Allows to generate synthetic data without requiring coding skills.*

Methods

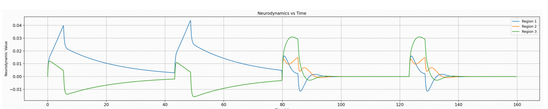
- **Bilinear Model:** Our framework uses a bilinear model [1] that spans three stages: neurodynamics, hemodynamics, and optics. This approach models the underlying neural activity, blood flow dynamics, and the resulting optical density changes captured by fNIRS signals.

Stimulus



Neurodynamics

$$\dot{z}_t = \left(A + \sum_{i=1}^{M} u_t(i) B^i\right) z_t + C u_t$$



Hemodynamics

$$\dot{s}_j = z_j - \kappa_j s_j - \gamma_j (f_{j,in} - 1)$$

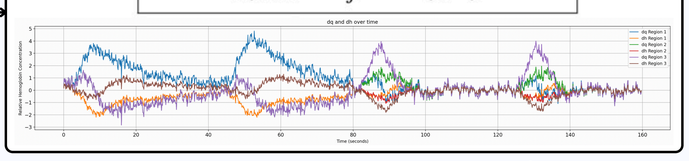
where $\dot{f}_{j,in} = s_j$

$$\tau_j \dot{v}_j = f_{j,in} - f_{j,out} \qquad \tau_j \dot{q}_j = f_{j,in} \frac{E(f_{j,in}, \rho)}{\rho} - f_{j,out} \frac{q_j}{v_j}$$

$$\tau_j \dot{p}_j = (f_{j,in} - f_{j,out}) \frac{p_j}{v_j} \qquad E(f, \rho) = 1 - (1 - \rho)^{1/f}$$

where

$$f_{j,out} = v_j^{1/\alpha} + \tau_{j,v} \dot{v}_j$$



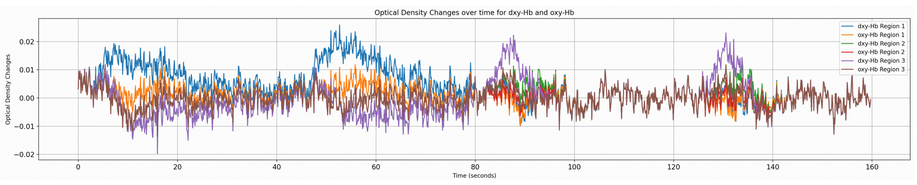
Optics

$$\begin{bmatrix} y(\lambda_1) \\ y(\lambda_2) \end{bmatrix} = \begin{bmatrix} \epsilon_H(\lambda_1) W_H S(\lambda_1) & \epsilon_Q(\lambda_1) W_Q S(\lambda_1) \\ \epsilon_H(\lambda_2) W_H S(\lambda_2) & \epsilon_Q(\lambda_2) W_Q S(\lambda_2) \end{bmatrix} \begin{bmatrix} \Delta H_c \\ \Delta Q_c \end{bmatrix},$$

where

$$K_l = \exp\left(-d_l^2 / 2\sigma^2\right)$$

$$\Delta H_c = pP_0 - qQ_0 - 2, \; \Delta Q_c = qQ_0 - 1,$$



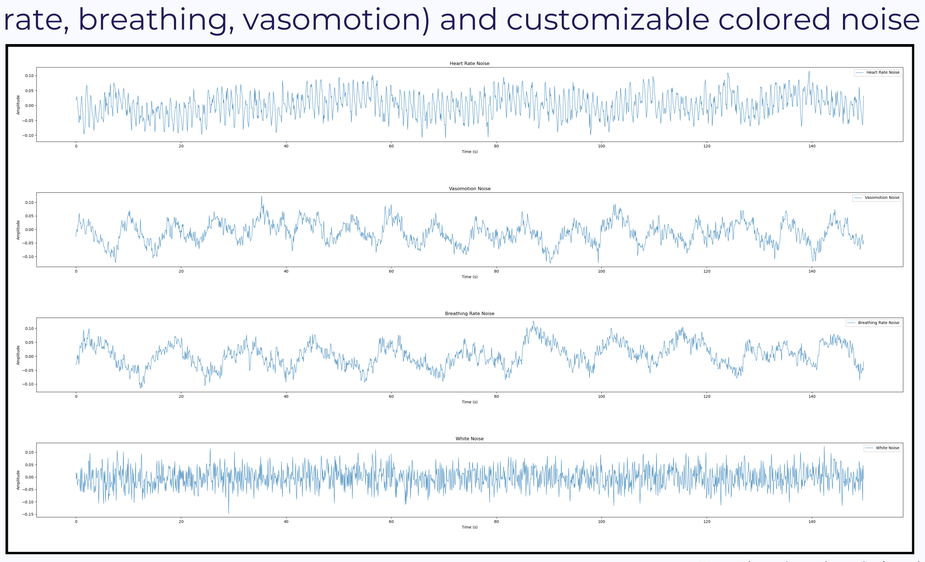
Results

- The framework generates datasets with synthetic or semisynthetic noise, supporting up to 10 regions. Users can select preset noises or integrate custom resting-state data. Controlled experiments confirm its realistic noise emulation capabilities.
- This framework significantly simplifies fNIRS synthetic data generation by combining a bilinear model with various noise generation options into a user-friendly interface.
- It provides researchers with a practical tool for simulating realistic neuroimaging scenarios, aiding in the validation of fNIRS data processing algorithms.

Usage

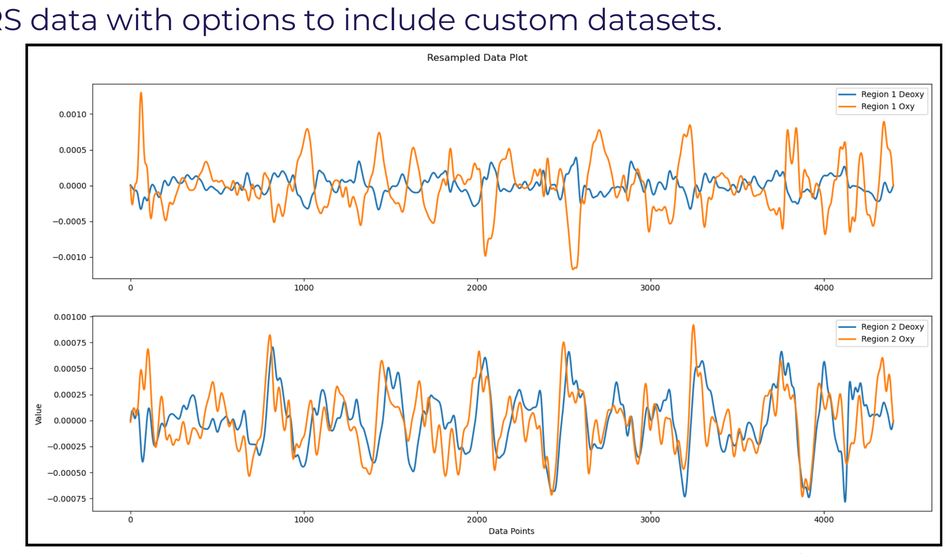
- Code-based installation implementation
  - *pip install bilinear-model-mdls*
- User-Friendly Interface
  - Easily generate and customize synthetic fNIRS data without coding experience.
- The ux-ui framework of this library can be found in:
  - *https://github.com/MarSH-Up/Bilinear-model*

- **Synthetic Noise Generation:** Includes physiological disturbances (e.g., heart rate, breathing, vasomotion) and customizable colored noise models.



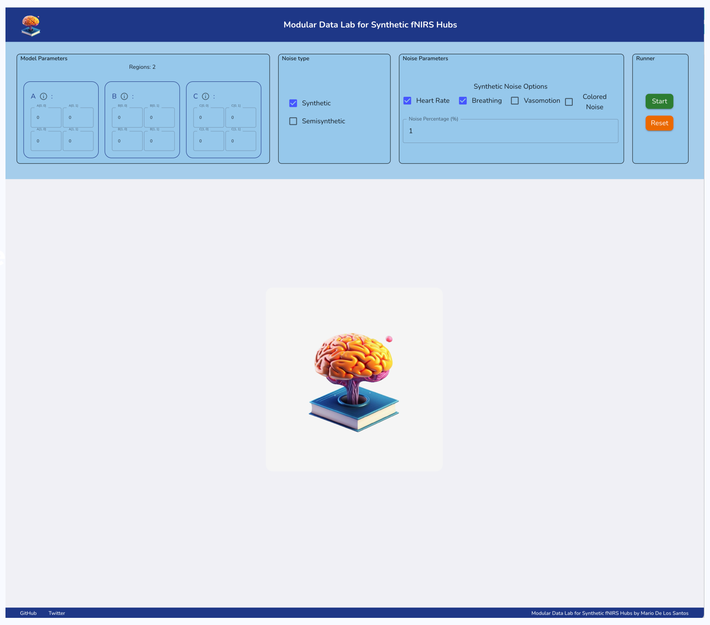
Synthetic physiological noises [2].

- **Semisynthetic Noise Generation:** Integrates precompiled resting-state fNIRS data with options to include custom datasets.



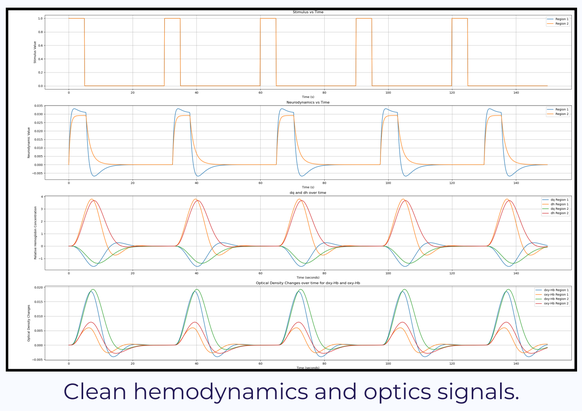
Semisynthetic noise, Montero S. [3].

- **Framework UX:** A graphical user interface allows users to generate synthetic and semisynthetic data, with control over signal-to-noise ratio (SNR), variability, and other noise characteristics.

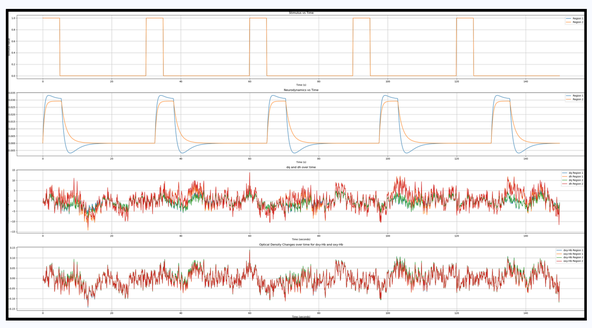


Quiz: Can You Spot the Difference?

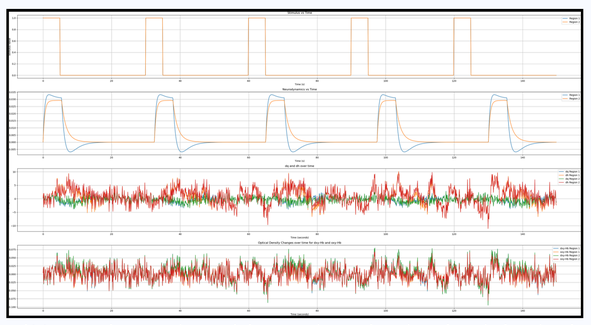
- Scan the QR code below to take the quiz and test your skills!



Clean hemodynamics and optics signals.



*Hemodynamics with synthetic physiological noise.



*Hemodynamics with semisynthetic physiological noise.

References
[1] Tak, S. et al. (2015). Neuroimage, 111, 338-349.
[2] Elwell, C. E. et al., In Oxygen transport to tissue XXI, 57–65 (1999).
[3] Montero-Hernandez, S. et al. (2018). Probabilistic Graphical Models Conference, pp. 296–307