System Modeling of Brain-Neuromuscular Functions for Developing Brain-Computer Interface

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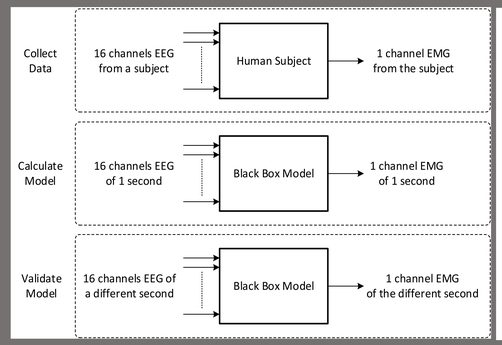
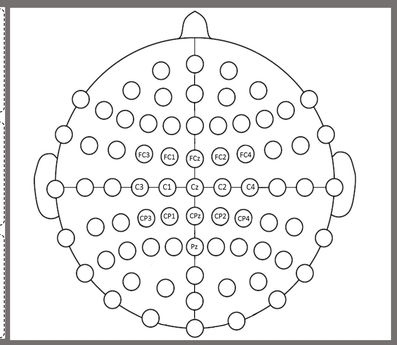
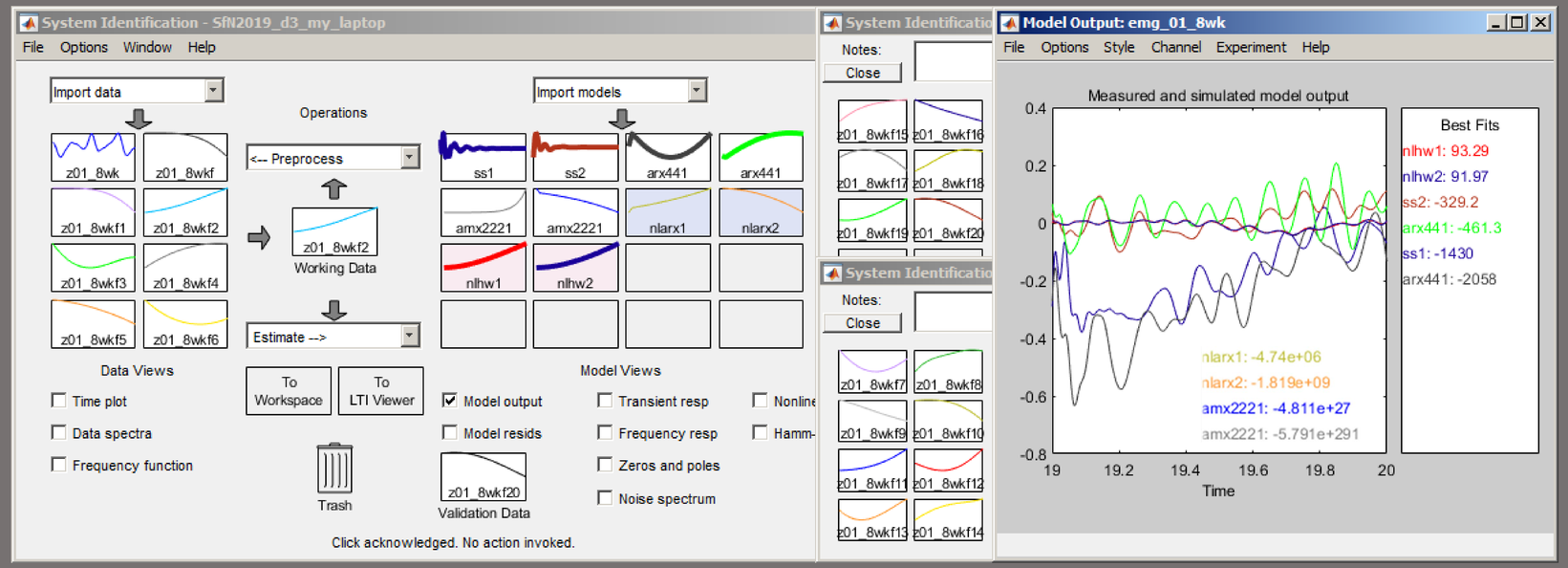
Introduction

- Brain-computer interface (BCI) has been developed for the purpose of bypassing the spinal cord and peripheral nervous system to communicate or control a remote device.
- Prospective designs have claimed to be able to assist people with severe disabilities or apply to the practice of neurorehabilitation.
- Due to the complicated and unpredictable nature of such systems, the feasibility and reliability of available BCIs remain to be fully explored.





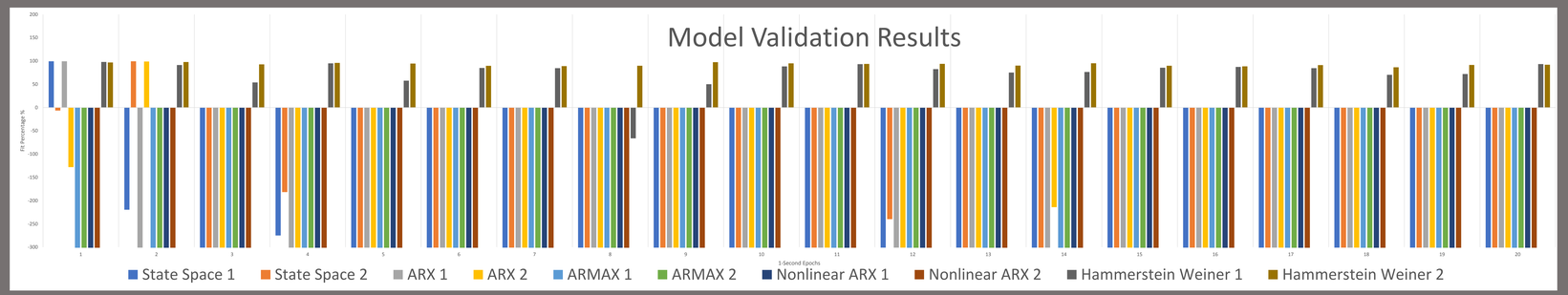


Method

- System identification techniques for black-box modeling were applied to find the most appropriate BCI system model.
- Encephalography (EEG) and electromyography (EMG) signals were acquired noninvasively from human subjects.
- The EEG and EMG signals were collected simultaneously while the subjects performed thumb isometric flexion at 50% maximal voluntary contraction for 20 seconds.
- Based on 16-channel EEG signals (actiCHamp) and a 1-channel EMG signal (Grass amplifier and CED AD board Power 1401) collected from the surface of the thenar eminence, we generated model criteria for
  - a state space model,
  - an autoregressive with external input (ARX) model,
  - an autoregressive moving average with external input (ARMAX) model,
  - a nonlinear ARX model, and
  - a nonlinear Hammerstein-Wiener estimation model.
- The models were calculated by using a 1-second epoch (2000 samples and bandpass filtered to focus on mu wave, 7.6 - 12.4 Hz) of the 1st and 2nd second of the 16-EEG/1-EMG signals.
- The models were validated by the other 18 1-second epochs (from 20 seconds of 16-EEG/1-EMG signals).

Results

- The one-way ANOVA indicates that the Hammerstein-Wiener estimation model performed significantly better (best fits > 90%, n = 18, $p < 0.001$) than the other models, suggesting that the more common polynomial models (ARX and ARMAX) are unfit for BCI development.
- Despite that the Hammerstein-Wiener estimation model performed the best among all the models included in this study, the massive computation power and time required to properly function may affect the development of BCIs based on this model.
- The current results may be the basis for future designs of BCIs and can be integrated into brain stimulation models for routine neurorehabilitation sessions.



Work in Progress

- Determine the relationship between EMG and force/motion.
- To include more EEG channels – greater brain area and spatial resolution.
- To include more EMG channels – to take more signals from different muscle groups into account.
- To include more system identification models.

References: 1. Lennart Ljung, System Identification: Theory for the User, 2nd ed., Prentice Hall: Upper Saddle River, NJ, 1999 2. MATLAB System Identification Toolbox, https://www.mathworks.com/products/sysid.html

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