BCI Prosthetic Literature Review

Neuroscience

EEG-based discrimination between imagination of right and left hand movement

- Imagining left and right hand movements
- The EEG was recorded bipolarly from left and right central and parietal regions

Relationship between speed and EEG activity during imagined and executed hand movements

- Neural activities involved with hand movement encode the direction, speed and other information
- The EEG activity in the alpha (8–12 Hz) and beta (18–28 Hz) frequency bands were found to be linearly correlated with the speed of imagery clenching.

A brain-computer interface that evokes tactile sensations improves robotic arm control

- Prosthetic hand gives tactile feedback to user's brain, cuts task time in half
- "There are about 169,000 people in the United States living with tetraplegia due to spinal cord injury (SCI)"
- "These artificial tactile percepts were driven in real time by sensors in a robotic hand that responded to object contact and grasp force (Fig. 1, C and D; and figs. S1 and S2), were evoked through intracortical microstimulation (ICMS) of area 1 of the somatosensory cortex, and were experienced as originating from the participant's own palm and fingers (fig. S1)."
- "This immediate performance improvement also demonstrates that ICMS in the somatosensory cortex was not akin to sensory substitution cues that could have been provided by electrical or mechanical stimulation of intact skin or audio or visual cues, because the relationship between these cues and behavior must be learned (31)."
- "many of the objects were rigid, and there was no penalty for grasping the objects too firmly. Tasks that involve fragile objects or more precise control of hand posture and grasp force could be more dependent on specific sensory encoding schemes."

Decoding individual finger movements from one hand using human EEG signals

- Movement from individual fingers can be identified using a BCI

Signal Processing

Brain-Machine Interfaces: Lessons for Prosthetic Hand Control

- Current state-of-the art: 5-30 degrees of freedom
    - Open/close hand: 1 degree of freedom

    - Move each finger in 1 pre programmed manner: 5 degrees of freedom
    - Move each joint in 1 pre programmed manner: ~15 degrees of freedom (3 joints / finger)
- Difficulties of EEG:
    - “low conductivity of bone and the exponential decrease in voltage gradients as the recording electrode becomes more distant further reduces the signal specificity and lowers the signal to noise ratios (SNR), making signal interpretation difficult”

Machine Learning Classification

Brain Computer Interface Issues and

- Details “Butterworth filter mechanism” to eliminate noise from EEG signals to enhance the data quality
- Feature extraction to transform raw signals into informative signals
- Location of brain signals for fist movements

Brain Computer Interface issues on hand movement

- Lists techniques of feature extraction

EEG-Based BCI System to Detect Fingers Movements

- Describes an ensemble learning approach with 5 one-class classifiers one for each finger.
- 81% classification accuracy for 5 test subjects
    - https://ieeexplore.ieee.org/abstract/document/9043565
    - Event-related desynchronization (ERD) topography during left or right index finger movement. A degree feature extraction algorithm was proposed based on the graph theory together with Support Vector Machine (SVM) to classify two kinds of index finger movement: left or right index finger movement. The average accuracy of the system was about 62%.
    - https://www.sciencedirect.com/science/article/pii/S0304394018309029
    - Proposed decoding finger movements, including four thumb-related movements as well as the flexion and extension movements of the index, middle, ring, and little fingers. The system predicts the movements using the Choi-Williams distribution and a two-layer classification framework. The system obtained an average classification accuracy computed over the four fingers across all subjects of 43.5%.
    - https://ieeexplore.ieee.org/abstract/document/8977037
    - proposed another system that applies the common spatial pattern (CSP) algorithm to extract features, as well as four classifiers, such as the random forest, SVM, k-nearest neighborhood (kNN), and the linear discriminant analysis (LDA) to discriminate between trials. The maximum average accuracy reached by these classifiers is about 54%.
    - https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0085192

    - Proposed using the principal component analysis (PCA), the Power Spectral Densities (PSD), and SVM with a Radial Basis Kernel Function (RBF). The average accuracy of the system was about 77%.

BCI systems that decode the movements performed by each finger within the same hand: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0085192

Wrist/grasp-related movements of the same hand:
https://www.sciencedirect.com/science/article/pii/S0304394018309029
https://ieeexplore.ieee.org/abstract/document/7192613

Previous EEG-based studies [7,8,9,10] were usually extracting features from the same group of electrodes for all subjects and for all fingers movements, whereas neuroscience studies mentioned that the activity is unique in the brain of each person. Moreover, the brain activity is different in the left and right brain hemispheres during the same motor imagery [7,21].

Fast and accurate decoding of finger movements from ECoG through Riemannian features and modern machine learning techniques

- We selected a set of informative biomarkers that correlated with finger movements and evaluated the performance of state-of-the-art ML algorithms on the brain-computer interface (BCI) competition IV dataset (ECoG, three subjects) and a second ECoG dataset with a similar recording paradigm (Stanford, nine subjects).

Decoding Hand Motor Imagery Tasks Within the Same Limb From EEG Signals Using Deep Learning

- improve the hand MI tasks decoding within the same limb in a brain-computer interface using convolutional neural networks (CNNs); the CNN EEGNet, LDA, and SVM classifiers were evaluated for two (flexion/extension) and three (flexion/extension/grasping) MI tasks

Motor imagery BCI classification based on novel two-dimensional modelling in empirical wavelet transform - Sadiq - 2020 - Electronics Letters - Wiley Online Library

- A different way to extract features of imported MI signals for an average classification accuracy of 95.2%.
- Uses empirical wavelet transform (EWT) to extract ‘modes’ from each signal
- These modes are then averaged in a 2D representation describing the distance and angle from the data to the overall average value
    - X and y coordinates can be given by distance and angle to provide a cartesian representation for all the modes in a given class.
- Can then distinguish the different classes by their 2D signatures given by the described model

Using brain connectivity metrics from synchrostates to perform motor imagery classification in EEG-based BCI systems - Santamaria - 2018 - Healthcare Technology Letters - Wiley Online Library

- Study that compares the accuracies of different algorithms in tracking the temporal changes in phase synchrostates in the left and right hand Motor Imagery signals
- Query directed clustering found to be most accurate

Real-time P300-based BCI in mechatronic control by using a multi-dimensional approach - De Venuto - 2018 - IET Software - Wiley Online Library

- Describes a three-part system architecture for acquisition of eeg data, processing via machine learning, and translation of "user intention" into actuation in a wheelchair
    - The ML portion of this study may prove less useful than other studies since it focuses on ERPs (event related potentials) where we want to generate actuation from spontaneous motor commands (sensorimotor rhythms?)

Hardware

Brain-Computer Interface Operation of Robotic and Prosthetic Devices

- Neuromuscular disorders that prosthetics can help: amyotrophic lateral sclerosis, brainstem stroke, cerebral palsy, and spinal cord injury
- Kinematic control vs. Goal selection: kinematic control requires three control signals continuously in real time, goal selection only needs final location

Creating a Working Brain-Controlled Transhumeral Prosthetic Arm (Make it Move)

- Useful for building the prosthetic, but beyond that it looks like the code is not open source so this is really just a source for hardware and not much beyond that

Electrode Placement

Review of Brain-Machine Interfaces Used in Neural Prosthetics with New Perspective on Somatosensory Feedback through Method of Signal Breakdown

100-electrode microelectrode array in the primary motor cortex (MI) contralateral to the arm used for the task of controlling the cursor (see Figure 2), and multiple forms of feedback were compared regarding the ability to control the arm.