Methods for development of a long-term human brain machine interface with the Neurotrophic Electrode

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Introduction
Research into the design and application of human brain machine interfaces (BMI) can be classified into two groups, those solving input problems or output problems. The input problem is primarily addressed by such devices as cochlear implants and retinal implants.

The output problem is classically thought of as a motor control problem, and both human and non-human primate motor cortical BMI have focused on restoration of visuo-motor movements, such as mouse cursor control and artificial limb control. Recent extensions of motor cortical BMI studies in our laboratory address speech and visuo-motor movements, such as mouse cursor control and artificial limb control.

This poster will detail the design considerations for human motor cortical BMI in general, with particular emphasis on speech motor control in experimental and real-world environments.

Overall design
Three components for human motor cortical BMI:

- Signal detection: Stable identification of putative action potentials from extracellular electrical recordings (discussed in Poster 779.9).
- Rate estimation: Quantification of neural firing patterns (e.g. rate measurement, spike arrival/inter-arrival times).
- Decoding method: Mapping from neural activity to intended behavior (e.g. cursor control, speech synthesizer control, etc.)

The use of the Neurotrophic Electrode and transcutaneous wireless telemetry in our research imposes additional considerations on the signal acquisition problem.

Signal detection
- Consistent spike identification required for stable neural decoding.
- Current use voltage thresholding for detection and manual convex-hull regions for classification.

Problem:
- Amplitude-based spike sorting is susceptible to hardware artifacts such as wireless signal strength, caused by: imperfections in transmission/reception RF and power induction coils.
- Changes in distance of reception and transmission coils due to variability of exact placement of coils for each session.

Resolution:
- Alternative detection methods
  - Amplitude-independent, or normalized-amplitude based methods
  - Utilize a robust, statistically sound approach
  - Incorporate redundancy (i.e. multiple methods running in parallel)
  - Adaptive, data driven detection and classification
  - Automated or hybrid-automatic spike sorting

Rate estimation
- Two main tasks:
  1. Spike arrival/inter-arrival times
  2. Firing rate estimation
     - Our current approach
- Problems:
  - Non-task specific global changes in firing rate
  - Possibly hardware related, or physiological

- Rate estimation yields mostly low-frequency information (i.e. smoothing)
- Ignores variance information of spike arrival/inter-arrival times

Resolution:
- Global normalization procedure during rate estimation.
- Kernel density method utilizing exponential function for smoothing kernel with adaptive exponential rate parameter

Global rate normalization
- (Left) Conventional 10ms window rate estimate (top) vs. adaptive exponential normalized rate estimate (bottom).

Decoding method
- Single unit coding and decoding in terms of motor control
  - E.g. Population vector algorithm, linear (Wiener) filter, Kalman filter (current choice)
  - Utilize relationship between firing rates and output variables
  - Speech output remarkably convenient; artificial computer speech synthesis

Summary
- Speech prosthesis can be treated as analogous to typical motor control BMI
- Convenient output modality for speech: artificial computer speech synthesis (no robotics necessary)
- Many outstanding issues to address for laboratory and real-world implementations
- System must be robust in wide ranging environments
- Parallel, redundant systems for spike sorting and signal decoding
- Continuous evolution of all three BMI components will be required for maintenance of signal and functional stability

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