DEVELOPING IMPLANT TECHNOLOGIES AND EVALUATING BRAIN-MACHINE INTERFACES USING INFORMATION THEORY

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ABSTRACT

Brain-machine interfaces (BMIs) hold promise for restoring motor functions in severely paralyzed individuals. Invasive BMIs are capable of recording signals from individual neurons and typically provide the highest signal-to-noise ratio. Despite many efforts in the scientific community, BMI technology is still not reliable enough for widespread clinical application. The most prominent challenges include biocompatibility, stability, longevity, and lack of good models for informed signal processing and BMI comparison.

To address the problem of low signal quality of chronic probes, in the first part of the thesis one such design, the Neurotrophic Electrode, was modified by increasing its channel capacity to form a Neurotrophic Array (NA). Specifically, single wires were replaced with stereotrodes and the total number of recording wires was increased. This new array design was tested in a rhesus macaque performing a delayed saccade task. The NA recorded little single unit spiking

activity, and its local field potentials (LFPs) correlated with presented visual stimuli and saccade locations better than did extracted spikes.

The second part of the thesis compares the NA to the Utah Array (UA), the only other micro-array approved for chronic implantation in a human brain. The UA recorded significantly more spiking units, which had larger amplitudes than NA spikes. This was likely due to differences in the array geometry and construction. LFPs on the NA electrodes were more correlated with each other than those on the UA. These correlations negatively impacted the NA's information capacity when considering more than one recording site.

The final part of this dissertation applies information theory to develop objective measures of BMI performance. Currently, decoder information transfer rate (ITR) is the most popular BMI information performance metric. However, it is limited by the selected decoding algorithm and does not represent the full task information embedded in the recorded neural signal. A review of existing methods to estimate ITR is presented, and these methods are interpreted within a BMI context. A novel Gaussian mixture Monte Carlo method is developed to produce good ITR estimates with a low number of trials and high number of dimensions, as is typical for BMI applications.