SIGNAL PROCESSING METHODOLOGIES TO MODEL THE RELATION BETWEEN SPIKE TRAINS AND HAND MOVEMENTS FOR BRAIN MACHINE INTERFACES

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The University of Florida Computational NeuroEngineering Laboratory (CNEL) is part of a five members consortium (Duke, MIT, SUNY, Plexon Inc.) lead by Duke University that is developing closed-loop brain machine interfaces (BMI). The ultimate goal is to allow patients suffering from paralysis or other neurological disorders to control robotic prosthetic limbs through thought.

One of the issues for the feasibility of BMIs is the bandwidth/accuracy achievable with EEG scalp recordings. Unlike these approaches, we are using invasive recording techniques pioneered by Nicolelis et al at Duke [1] to test their suitability to build BMIs. Spike trains from large arrays of microwire electrodes implanted in the pre motor, primary motor and posterior parietal cortices of nonhuman primates are recorded at Duke University while the primates performed 3-D reaching tasks. These recordings of large neuronal assemblies provide mesoscopic information while maintaining high temporal and spatial resolution. Electrode outputs processed by spike detection and sorting techniques yield firing patterns of up to 104 single neurons. For real-time processing of the data, neuronal firing counts in 100ms windows are used as inputs from which control signals are derived.

The translation of these signals into control commands is approached both from an input-output (I/O) modeling framework and from a state estimation perspective. We assume there exists an unknown system that maps the firing counts to hand position in 3-D space, and by observing the inputs and outputs we can optimally adapt the model to approximate the desired relationship. The CNEL lab has investigated three I/O models: Wiener filtering, switching local linear models, and nonlinear recurrent neural networks (RNN). The Wiener filter assumes a linear relationship between the neuronal firing counts and hand position. The filter output is simply a weighted sum of delayed versions of the firing counts achieved by optimal projection to a linear space. The multiple linear model method assumes that the firing counts that produce a desired hand trajectory are piecewise stationary. Multiple linear FIR filters are trained in parallel and compete to become specialized for each piecewise stationary segment. The RNN adapts a nonlinear model to map firing counts to hand position. This model is a modified version of the multilayer perceptron (MLP) and contains feedback connections in its hidden layer. State feedback allows for continuous representations on multiple timescales and is a powerful method to extract temporal information from neuronal firing counts. The state estimation approach uses a Kalman filter to model the hand position, speed and acceleration as states given the spike trains as noisy observations.

The framework for assessing the results of a BMI is not yet fully established. Model performance to predict hand position from neuronal firing counts is evaluated with three different measures: correlation coefficient, signal to error ratio (SER), and target acquisition plots. The correlation coefficient computed over sliding windows quantifies how well the actual and predicted hand trajectories are linearly related. The SER, defined as the square of the desired signal divided by the square of the estimation error, gives a measure of the accuracy of estimated position in terms of the error variance. The third measure is a graphical technique which places the target location at the center of a 3-D coordinate system. The error associated with each direction (x, y, z) is plotted on its respective axis. Errors that form a tight cluster of points around the target indicate successful target acquisition.

In this presentation I will present comparisons among all these models and raise some of the important signal processing problems in this approach.

[1] Wessberg, J., C. R. Stambaugh, J. D. Kralik, P. D. Beck, M. Laubach, J. K. Chapin, J. Kim, S. J. Biggs, M. A. Srinivasan and M. Nicolelis (2000). "Real-time prediction of hand trajectory by ensembles

of cortical neurons in primates." *Nature* 408(6810): 361-365.

A MINIATURE, WIRELESS TWO-CHANNEL EEG FOR BRAIN COMPUTER INTERFACE

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A new, low noise, two-channel wireless data acquisition system used to monitor electroencephalogram (EEG), on humans for research purposes has been developed by Cleveland Medical Devices Inc. It is called the BioRadio® Jr.

The system consists of a small compact integrated transmitter with a form factor that can be used on a headband, or mounted on a hairpin. The device includes, two preamplifiers, two amplifiers, a state-of-the-art analog to digital (A/D) converter, a microprocessor, and a MicroSynth™ RF radio transmitter. It weighs less than one-half ounce, is 1.3” x 0.9” x 0.3” in size, and can transmit digital EEG signals to a nearby receiver to a distance of about 50 feet through walls. This 50-foot range allows users to be untethered, allowing them to move freely about the bed, home, lab, or ward without entangling wires.

The receiver attaches to the serial port of any personal computer (PC). The data stream format at the serial port is available to users to be interfaced with other Brain Computer Interface (BCI) software. Data can also be viewed in real-time using BioCapture software and simultaneously saved to the PC hard drive. ASCII conversion tools allow data analysis in software packages such as MATLAB®, LabVIEW™, Excel, and .edf sleep software.

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