

## A REAL-TIME BRAIN-MACHINE INTERFACE COMBINING PLAN AND PERI-MOVEMENT ACTIVITIES

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Brain-machine interfaces (BMI) map relevant neural activities to the intended movement, known as 'decoding'. Information about various states of a movement are encoded in the motor areas. These include the kinematic states such as velocity and higher level states such as the intended target. Real-time BMIs have mostly focused on decoding individually either the goal of a movement or its kinematics. However, for goal-directed movements, target information can greatly improve the kinematics decoding.

We consider real-time decoding of goal-directed movements with *unknown* duration. We develop a recursive Bayesian decoder that takes advantage of the goal information to reduce the root mean-square (RMS) error in movement trajectory reconstruction. Our decoder has two major components. The first component builds a new state-space model for the kinematics by exploiting the optimal feedback control model of the sensorimotor system. This contrasts with prior work that has used smoothed random-walk (RW) or open-loop controlled models. Any goal-directed model inherently depends on the movement duration not known a priori to the external observer of the neural signal. To be practical, the second component of our decoder addresses this timing uncertainty in contrast to other work that assumes it is known. This is done by exploiting a bank of parallel point-process filters (P-PPF) that calculate not only causal estimates of the state at each time based on the neural activity, but also the likelihood of the movement duration based on this activity. The overall decoder is a feedback-controlled P-PPF (FC-P-PPF).

We first tested our decoder on the simulated neural spiking activity of 20 neurons generated in response to 55 actual reaching movements of 150-400 ms duration performed by a rhesus monkey. This activity was simulated using the velocity tuning model. We found that FC-P-PPF reduced the RMS error in trajectory reconstruction from that of the RW point-process filter by 40%.

We then implemented a real-time BMI exploiting FC-P-PPF in an instructed-delay center-out task with 4 targets performed by a monkey. Multi-electrode spiking activity was recorded from the dorsal premotor cortex (PMd) and supplementary motor area (SMA) from which 19-20 cells were isolated. Our real-time BMI had two phases and combined *two* algorithms: 1. During the instructed delay, a maximum-likelihood decoder was used to decode the upcoming target from the plan ensemble spiking activity modeled as a point-process for each neuron. 2. After the delay period, the BMI transitioned into the kinematics decoding phase, exploiting the decoded target in FC-P-PPF. The peri-movement ensemble spiking activity in this phase was modeled and fit as a point-process tuned to velocity and position for each neuron. The estimated cursor position was displayed on the screen in real-time.

We measured performance as the percentage of trials with the target correctly acquired. For this monkey, the performance was 73% - 87% with an average of 82% across multiple sessions using only 19-20 cells. The average correct acquisition time was about 1 s. From our real-time experimental results we conclude that properly combining plan and peri-movement activities improves the performance of BMIs.