AN ABSTRACT OF THE THESIS OF

Damon A. George for the degree of Master of Science in Computer Science presented on August 9, 2021.

Title: Adaptive Movement Intent Decoding for Intuitive Control of Neuroprostheses

Abstract approved: ______________________________

V John Mathews

In the United States alone, around 2 million people live with limb loss and another 5 million live with some form of paralysis. Movement intent decoders, which interpret volitional movement intent from human bioelectric signals, can be incorporated into prosthetic systems to offer such individuals the potential to regain their lost motor control and greatly increase their standard of living. Modern machine learning methods have become the research standard for continuous decoders with high degrees of freedom (DoFs), but these methods suffer from performance deterioration over time because the human body is a time-varying system, whereas these decoders are typically fixed after initial training.

To tackle the issue of performance deterioration in modern neuroprostheses, this thesis presents a novel formulation and real-time framework for neural network-based online learning decoders, which adapt the decoder parameters to changes in the user's bioelectric signals. This formulation incorporates label estimation for creating semi-supervised training labels during the decoder's normal operation, and online learning with replay for updating the decoder parameters in a stable manner using those label estimates. The real-time adaptive decoding framework consists of (i) a neural network architecture allowing asynchronous parameter updates for each DoF, (ii) a novel adaptively-scaling real-time Dynamic Time Warping (DTW) algorithm for detecting movements in each DoF, (iii) a least-squares algorithm to estimate trajectories for detected movements, (iv) a cross movement filter to reject estimated but undesired simultaneous movements in the DoFs, and (v) a multiprocessing software framework to enable the online operation of this adaptive system.

This thesis applies the adaptive decoding framework to the control of prosthetic hands using surface electromyograms (EMG), a non-invasive measurement of muscle contractions. After testing the label estimation methods on simulated movements perturbed with noise, and with approval from the Institutional Review Board at Oregon State University, the adaptive decoding framework was evaluated in two separate experiments using intact-arm volunteer subjects. A *short-term* experiment collected two sessions of data from 10 subjects, in which movement prompts were designed to produce fatigue over 25 minutes. This experiment tested the ability of the adaptive decoder to adapt quickly to short-term physiological changes. A *medium-term* experiment recorded weekly datasets from 5 subjects over the course of 6 weeks to determine the adaptive decoder's ability to reduce performance deterioration over a longer time span. The weekly sessions tested three decoder variations: the adaptive decoder trained in the first week, the corresponding non-adaptive decoder, and a decoder which was retrained each week as a performance baseline.

In the *short-term* experiment, the non-adaptive decoder exhibited a significant 5% drop in success rate due to fatigue from the first to second half of the testing sessions, whereas the adaptive decoder showed no obvious performance degradation and significantly outperformed the non-adaptive decoder in the second half. In the *medium-term* experiment, the three decoders showed statistical differences. The retrained decoder showed the best performance, with no significant changes over time, whereas the non-adaptive decoder performed the worst, dropping from 64% to 25% success rate over the 6 weeks. The adaptive decoder halved the rate of performance deterioration in the non-adaptive decoder, but was still significantly worse than the retrained decoder. Finally, offline analyses showed that the DTW-based movement detection and least-squares trajectory estimation methods developed in this thesis outperformed existing baselines by over 10% in their label estimation error.

The adaptive decoder presented in this work did not eliminate all performance deterioration (the ultimate goal), but it successfully slowed the rate of deterioration. With this framework, periodic retraining of decoders would still be required for commercial prostheses. However, this adaptive framework could significantly extend the time between retraining, making these prostheses more usable and reducing the likelihood of rejection. In addition, this adaptive decoding formulation opens up the door to many paths for future research and improvement of adaptive decoders for continuous, intuitive control of neuroprostheses.