Electromyographic Signal Processing With Application To Spinal Cord Injury

Thesis by

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In Partial Fulfillment of the Requirements
for the Degree of
Doctor of Philosophy

Caltech

California Institute of Technology
Pasadena, California

2016
(Defended March 21, 2016)

To Teresa, for her endless support and love.

Acknowledgments

It gives me great pleasure to acknowledge the many people whose work, advice and support have helped me during my Ph.D. over the last six years.

Foremost, I would like to thank my advisor, Prof. Joel Burdick. He gave me the opportunity of working on Electromyogram (EMG) processing, which made me realize how much l Iike programming and algorithm development. I still clearly remember the “brick and wall” example he used to illustrate how to approach a problem when I first started working in his group. I find that really useful in many different areas of my life, not just research. During my time working with him, Prof. Burdick has always been very supportive, kind and generous. Without him, I couldn’t have made it here.

I would also like to thank my research group for numerous discussions on my research. I would like to thank Jeffrey Edlund in particular because he showed me to the world of EMG processing when I first started. I’ve learnt a lot from him, especially about programming, and he contributed many of the codes used in EMG processing.

Thank you to my collaborators at University of Louisville at Kentucky for their support and discussions on my research and I’m especially grateful for their warm reception during my visit there.

I’m very thankful for all the suggestions from my committee members, Prof. Hyuck Choo, Prof. David Rutledge, Prof. Pietro Perona, Prof. Changhuei Yang and Prof. Reggie Edgerton.

I would also like to thank my parents. Without them, I couldn’t come to pursue graduate study at Caltech. Even though they are far away in China, their support and love have been invaluable to me during my life at Caltech.

Last but not least, I’d like to thank my fiancee, Teresa Liu, for her great and constant support for my Ph.D. life at Caltech. She helped me solve numerous problems I encountered during my road to graduation. Without her love and encouragement, I definitely wouldn’t be finishing this thesis.

Abstract

An Electromyogram or Electromyographic (EMG) signal is the recording of the electrical activity produced by muscles. It measures the electric currents generated in muscles during their contraction. The EMG signal provides insight into the neural activation and dynamics of the muscles, and is therefore important for many different applications, such as in clinical investigations that attempt to diagnose neuromuscular deficiencies. In particular, the work in this thesis is motivated by rehabilitation for patients with spinal cord injury. The EMG signal is very important for researchers and practitioners to monitor and evaluate the effect of the rehabilitation training and the condition of muscles, as the EMG signal provides information that helps infer the neural activity in the spinal cord. Before the work in this thesis, EMG analysis required significant amounts of manual labeling of interesting signal features. The motivation of this thesis is to fully automate the EMG analysis tasks and yield accurate, consistent results.

The EMG signal contains multiple muscle responses. The difficulty in processing the EMG signal arises from the fact that the transient muscle response is a transient signal with unknown arrival time, unknown duration, and unknown shape. In addition, the EMG signal recorded from patients with spinal cord injury during rehabilitation is very different from the EMG signal of normal healthy people undergoing the same motions. For example, some of the muscle responses are very weak and thus hard to detect. Because of this, general EMG processing tools and methods are either not applicable or insufficient.

The primary contribution of this thesis is the development of a wavelet-based, double-threshold algorithm for the detection of transient peaks in the EMG signal. The application of wavelet transform in the detection of transient signals has been studied extensively and employed successfully. However, most of the theories assume certain knowledge about the shapes of the transient signals, which makes it hard to be generalized to the transient signals with arbitrary shapes. The proposed detection scheme focuses on the more fundamental feature of most transient signals (in particular the EMG signal): peaks, instead of the shapes. The continuous wavelet transform with Mexican Hat wavelet is employed. This thesis theoretically derived a framework for selecting a set of scales based on the frequency domain information. Ridges are identified in the time-scale space to combine the wavelet coefficients from different scales. By imposing two thresholds, one on the wavelet coefficient and one on the ridge length, the proposed detection scheme can achieve both high recall and high precision. A systematic approach for selecting the optimal parameters via simulation is proposed and demonstrated. Comparing with other state-of-the-art detection methods, the proposed method in this thesis yields a better detection performance, especially in the low Signal-to-Noise-Ratio (SNR) environment.

Based on the transient peak detection result, the EMG signal is further segmented and classified into various groups of monosynaptic Motor Evoked Potentials (MEPs) and polysynaptic MEPs using techniques stemming from Principal Component Analysis (PCA), hierarchical clustering, and Gaussian mixture model (GMM). A theoretical framework is proposed to segment the EMG signal based on the detected peaks. The scale information of the detected peak is used to derive a measure for its effective support. Several different techniques have been adapted together to solve the clustering problem. An initial hierarchical clustering is first performed to obtain most of the monosynaptic MEPs. PCA is used to reduce the number of features and the effect of the noise. The reduced feature set is then fed to a GMM to further divide the MEPs into different groups of similar shapes. The method of breaking down a segment of multiple consecutive MEPs into individual MEPs is derived.

A software with graphic user interface has been implemented in Matlab. The software implements the proposed peak detection algorithm, and enables the physiologists to visualize the detection results and modify them if necessary. The solutions proposed in this thesis are not only helpful to the rehabilitation after spinal cord injury, but applicable to other general processing tasks on transient signals, especially on biological signals.

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