Chapter 5

Conclusion

5.1 Summary of Thesis Contributions

The primary contribution of this thesis is the development of a set of automatic, unsupervised tools for the analysis of Electromyogram or the EMG signal for the purpose of studying electrical stimulation based rehabilitation on patients with spinal cord injuries. A wavelet-based, double-threshold algorithm was developed for the detection of transient peaks in the EMG signal (Chapter 3). Based on the transient peak detection result, EMG signals are further segmented and classified into various groups of monosynaptic MEPs and polysynaptic MEPs using techniques stemming from Principal Component Analysis (PCA), hierarchical clustering, and Gaussian mixture model (Chapter 4). 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.

Although there exist many different sets of tools to analyze the EMG signal, most of them rely greatly on the human supervision. One significant aspect of the contributions of this thesis is that all the proposed analysis methods are completely automatic and unsupervised. This is particularly important when the amount of data is huge, or real-time processing is desired. The EMG signal of interest in this thesis was recorded from patients with spinal cord injuries during the rehabilitation under electrical stimulation. As a result, the EMG signal is very different in nature from most of the signals in the EMG community. The EMG signal dealt with in this thesis has more complicated shapes, and the shape information is not a known priori. As a result, the set of methods developed in this thesis made no assumptions on the shapes of the signals, and therefore can be applied to any generic transient signals, as long as the transient signals are composed of peaks, which is the case in most practical systems, such as ECG signals, and mass spectrum.

Chapter 3 extends existing theories in the transient detection field. The application of wavelet transform in the detection of transient signals has been studied extensively and employed successfully. However, most of the theories assumes certain knowledge about the shapes of the transient signals, which makes it hard to be generalized to 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 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.

In Chapter 4, a method for automatically segmenting and clustering the detected EMG signal is derived. A theoretical framework is proposed to segment the EMG signal based on the detected peaks. The scale information of the detected peaks 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 Motor Evoked Potentials (MEPs). Principal component analysis (PCA) is used to reduce the number of features and effect of the noise. The reduced feature set is then fed to a Gaussian mixture model (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.

In order to make the processing completely unsupervised, the statistics of the underlying noise must be estimated automatically and accurately. Assume the noise is White Gaussian Noise (WGN), from robust statistics, the variance of the noise can be estimated if the signals are outliers. In the case that signals are not outliers, the performance deteriorates rapidly. An iterative algorithm has been proposed to improve the accuracy of the estimation even when the signals are not outliers, and simulated experiments show great boost in the accuracy.

5.2 Opportunities for Future Work

The key difficulty in processing the EMG signal is the complex structure of the transient signals (MEPs in the case of the EMG signal in this thesis). The lack of prior knowledge on the shape of the transient signals makes the detection and further processing very difficult. In this thesis, transient signals are modeled as consecutive transient peaks. Based on this model, detection and segmentation methods are derived. In the future work, better representation of the transient signals can be explored and employed to formulate new detection and segmentation scheme. For example, Le's proposed idea of using L-spline functions to model transient signals is promising [29].

The parameters in the proposed peak detection method are selected based on simulated experiments. In the future work, the parameters can be theoretically derived. In the segmentation, the effective support of the mother wavelet is chosen to be the width of the its most significant peak. Other choices may yield better results, and is subject to more theoretical development. A Bayesian clustering can be derived in order to incorporate the prior knowledge for better clustering results. Lastly, the noise is assumed to be additive white Gaussian. Other noise models may be explored. The proposed peak detection method is formulated as a generic detector with little assumptions made on the transient signals. As a result, the work in this thesis can potentially be applied to any transient signals that are composed of transient peaks, especially biological signals such as the electrocardiogram (ECG).