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A training strategy to reduce classification degradation due to electrode displacements in pattern recognition based myoelectric control

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Abstract

Pattern recognition based myoelectric control systems rely on detecting repeatable patterns at given electrode locations. This work describes an experiment to determine the effect of electrode displacements on pattern classification accuracy, and a classifier training strategy to accommodate this degradation. The results show that electrode displacements adversely affect classification accuracy, but training the system to recognize plausible displacement locations mitigates the effect. Furthermore, a combination of time-domain and autoregressive features appears to yield the best classification accuracy and is least affected by electrode displacements.

Keywords: EMG; Myoelectric control; Pattern recognition; Powered prostheses; MES

1. Introduction

Information extracted from multi-channel surface myoelectric signal (MES) recording sites can be used as inputs to control systems for powered prostheses. Myoelectric control systems can be loosely grouped into two categories; (1) conventional myoelectric control, and (2) pattern recognition based myoelectric control strategies. Conventional myoelectric control strategies have found widespread clinical use and have evolved to be used in conjunction with body powered harnesses, mechanical switches, and force sensitive resistors as part of an overall conventional prosthesis control strategy.

When fitting conventional prostheses it is common to embed electrode pairs in the prosthesis socket such that a bipolar channel is located over a muscle remaining on the residual limb. For transradial amputees, a common electrode placement would be one bipolar channel over the wrist flexors muscle group and one bipolar channel of the wrist extensor muscle group. A clinician would then instruct an amputee to produce muscular contractions to determine an appropriate MES amplitude threshold to activate the device. This type of conventional control strategy has proven to be relatively impervious to slight electrode displacements associated with socket/residual limb misalignments, as relatively coarse amplitude information is used.

Pattern recognition based myoelectric control systems operate on the assumption that at a given set of electrode locations, the set of features describing the myoelectric signals will be repeatable for a given state of muscle activation and will be different from one state of activation to another [1]. This form of myoelectric control has been implemented successfully by a number of groups in a controlled research setting; however, it has seldom been implemented clinically. Consequently, long term robustness issues, including sensitivity to electrode displacements, have rarely been considered.

Generally, pattern recognition based myoelectric control can be considered a supervised classification problem; training data are collected during a controlled experiment and a set of class labels are appropriately assigned to train the system. It is important that a wide variety of exemplars are presented to the classifier during the training phase so that it will generalize to new patterns presented during normal operation. This can be challenging for myoelectric control problems because the measured myoelectric signal changes for a variety of reasons. In a clinical setting it is important to complete the training data collection in a reasonable amount of time for the comfort of

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both clinician and patient. Normally, training data are collected only from the nominal electrode placements (the location where the electrodes rest when the socket is in perfect alignment), and no effort is made to incorporate displacement locations which may be present due to socket/residual limb misalignment.

Intuitively, one would expect that electrode displacement would cause changes in the response of the control system; however, Hudgins et al. [2] found that shifts of up to 2 cm had relatively little effect on classification accuracy of a 5-class myoelectric control problem (elbow flexion, elbow extension, hand open and hand close). To obtain these results, a single bipolar channel of MES data were collected where one electrode was placed on the biceps and one electrode was placed on the triceps. Hudgins suggested that the electrode shifts were small in comparison to large the interelectrode distance and in both cases the electrodes were recording the global activity of the biceps and triceps.

Hargrove et al. [3] found that shifts of 1 cm from a nominal training position reduced classification accuracy from approximately 90 to 60% for a 10-class myoelectric control problem. When a classifier was trained to recognize plausible displacement locations, this classification accuracy dropped to only 85%. To obtain this result, four closely spaced bipolar (interelectrode spacing of 2 cm) channels were collected.

The results of these two studies imply that the classification accuracy changes due to electrode displacements are affected by interelectrode spacing, the number of electrodes used in making classifications, and the number of motions classified. It should be noted in both previously mentioned cases time-domain (TD) features were chosen to represent the MES waveforms. Furthermore, in each of those experiments, the electrodes were re-applied at displacement locations prior to collecting test data. Consequently, it was impossible to separate the classification error solely due to the electrode displacements from inevitable variability in the MES due to 'operator error' (slight differences in contraction patterns, and the inherent variability of the MES). This experiment is meant to investigate the effect of electrode displacements on classification accuracy for selected wrist and hand motions. Nominal and displacement data will be collected simultaneously using a high-density electromyography system to remove the effect of the operator error.

2. Experiment

2.1. Methods

When assessing classification accuracy of pattern recognition based myoelectric control, bipolar electrode pairs are typically placed in nominal locations over areas of interest. However, to accomplish the goal of assessing the effect of electrode displacement, five constellations consisting of ten monopolar electrodes (Fig. 1a) were applied to the upper forearm (Fig. 1b). The interelectrode spacing in the constructed bipolar pairs was 3 cm, and displacement electrodes were located 1 cm from the center electrodes at 45°. The nominal electrode position would be constructed by taking difference between electrode C and H. This electrode location corresponds to the center of the constellation and would be the expected location of the recording electrode during the day-to-day operation of the prosthesis. Shift locations correspond to the differences between AF, BG, DI and EJ, assuming a rigid bipolar electrode pair. These locations represent plausible worst case possible displacement locations if there was socket/electrode misalignment. Thus, by recording the monopolar channels from the constellation, four displacement locations could be investigated without having the subject repeat the motions separately for each displacement situation. This removes 'operator error' from the analysis.

A high density EMG system (TMS International REFA 128) which is capable of collecting up to 128 monopolar MES channels was used to collect MES data from four normally limbed subjects to with electrodes placed to model long transradial amputees. The experimental protocol was approved by the University of New Brunswick's Research Ethics Board.

For consistent electrode placement, each subject was instructed to place their right arm in a fully supinated position on a table. Next, constellation 1 was placed on the top of the forearm (12 o'clock position), approximately 1/3 the distance from the

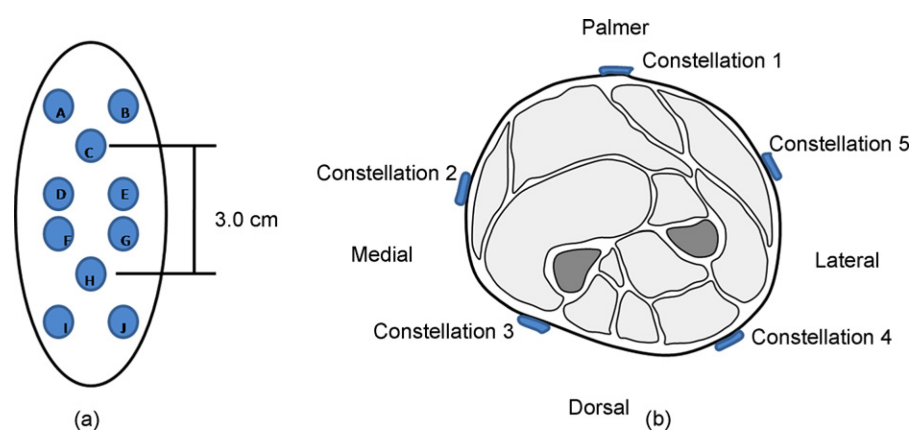

Fig. 1. (a) An example of the monopolar electrode constellation used to investigate electrode displacements. Bipolar spatial filters were created offline using C–H, A–F, B–G, D–I, G–J. (b) Each constellation was placed 1/3 the distance between the elbow and wrist at the locations shown above.