Myoelectric signals improve performance in force matching task

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Abstract

The purpose of this research was to assess the performance of a myoelectric-assisted controller used in a tracking task. Using the index finger, a subject tracked force profiles displayed on a screen using visual feedback from two different controllers: 1) the actual force and 2) the myoelectric controller. The myoelectric-assisted controller performed significantly better than using feedback from the force measurements (p = 0.00001). The myoelectric controller provided a 14% improvement over the force feedback during dynamic finger movements and performed just as well during static finger tasks. These findings provide evidence that combining myoelectric signals with mechanical sensors improves man-machine interfaces for biomechanical movements and force control.

1. INTRODUCTION

Myoelectric signals have been integrated in many applications over the years to provide control of prosthetic limbs [1], for functional neuroprostheses [2], and for teleoperation of robotic devices [3]. Many experimental techniques and algorithms have been developed in an attempt to further improve the ability to predict forces and torques from these myoelectric signals. Adaptive filters [4], artificial neural networks [3] and frequency spectrum classifiers [5] (to name a few) have been used to improve both the speed and the accuracy of these predictions. However, it has been challenging developing strictly myoelectric based controllers that respond quickly and can accurately provide stable and accurate control. In lieu of relying entirely on myoelectric signals for control, this research examines the feasibility of combining myoelectric signals with mechanical sensors to assist virtual control. The purpose of this research is to assess the performance of a myoelectric-assisted controller used to regulate finger force.

2. METHODS

The experiment required a subject to track force profiles displayed on a screen by generating isometric finger movements with the dominant index finger, thereby minimizing the difference between the target and the actual response. To assess the feasibility of using the myoelectric controller, the experiment was performed on a trained able-bodied subject.

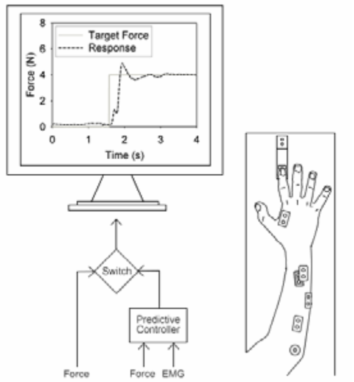

Figure 1: *Experimental setup. Five EMG electrodes are drawn. The shaded electrode is located on the inner arm. The ground is the circular electrode.*

2.1. Recordings

Finger force was measured using a load cell (Elane Electronic) placed under the tip of the index finger of the dominant hand. Prior to analogue-to-digital conversion, the data was filtered using a first order Butterworth low-pass filter with a cut-off frequency of 400 Hz. In real-time, the data was further filtered using a first order 33 point (16.5 ms delay) Savitzky-Golay filter. The myoelectric activity involved in generating finger force was measured using surface electromyography (EMG) techniques. Five EMG electrodes were placed on accessible sites of the hand and arm to capture myoelectric activity from the flexor digitorum superficialis, flexor digitorum profundus, extensor indicis, extensor digitorum, and first dorsal interosseous

(Fig. 1). The signals were amplified and filtered with a 10-1000 Hz bandwidth using an eight-channel EMG pre-amplifier (Bortec Biomedical Ltd.).

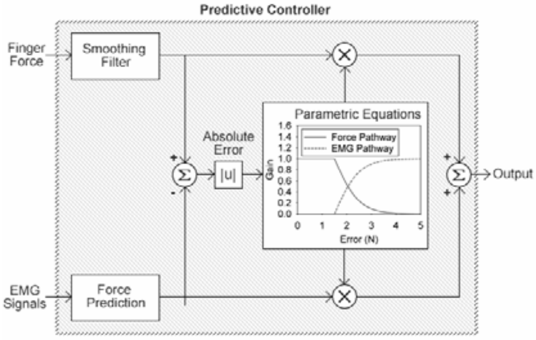

Figure 2: *Schematic of the predictive controller. The controller compares the force measurements with the EMG-based predictions to adjust the gain element in each pathway.*

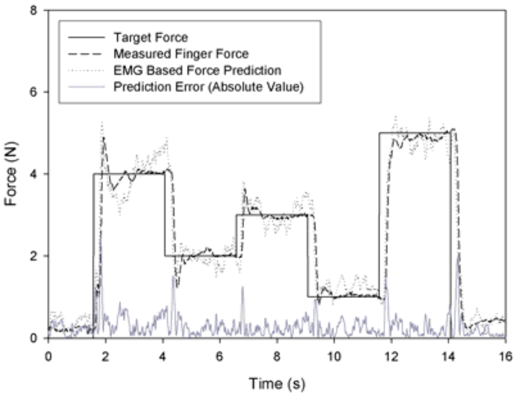

Figure 3: EMG-based force predictions during the experiment. The spikes in the prediction error reveal the effects of phase separation during the rapid movements.

2.2. Predictive force model

Previous experiments in our lab have revealed that isometric finger forces can be modelled from EMG activity using the Laguerre Expansion Technique (LET). The Laguerre expansion involves using an orthogonal set of Laguerre functions to develop finite-impulse digital filters (i.e. one per muscle) which effectively filter the rectified EMG signals to predict the force. As anticipated, the resulting model is less accurate than measuring finger force; however, since muscular activity is a necessary precursor to motor movements, the EMG-based model can be adjusted to respond faster than the actual finger movements. The model was calibrated to predict finger force 50 ms before the movement begins.

2.3. Myoelectric-assisted controller

A myoelectric controller was developed in an attempt to improve force control (Fig. 2). The controller uses: 1) the measured forces from the load cell and 2) the predicted forces calculated from the EMG-based predictive model. This controller acts as a proportional gain controller by calculating the difference between both inputs (force and predicted force) and adjusting the two variable-gain elements accordingly. The controller works on the principle that phase separation between two similar signals varies linearly with frequency. A delay between two low frequency signals has negligible effect on the phase separation. However, a delay, and hence, a phase separation becomes significantly more apparent when comparing higher frequency signals. In this study, as the difference between the measured force from the load cell and the predicted force (signal 50 ms ahead) increases, this indicates that the finger is moving quickly. Conversely, when the difference is small, the finger is moving slowly. Together, the force measurements and the fast-acting EMG-based predictions were used to help improve the overall tracking performance. The controller's two gain elements were adjusted using two equations that varied according to the error between both signals:

$$y(x) = \begin{cases} 1 & x \leq 1.5 \\ 1 - \tanh(x - 1.5) & x > 1.5 \end{cases}$$

$$z(x) = 1 - y(x)$$

where x is the absolute error and y and z represent the gains for the measured force and the EMG-based predictions, respectively. When the error x between target force and the response is less than 1.5 N, the controller uses information uniquely from the force sensor. As the error increases thereafter, the controller begins using a combination of both the measured force and the EMG-based predictions.

2.4. Experimental Protocol

To avoid aliasing of the EMG signals, all experiments were performed using real-time feedback working at 2000 Hz. The trained subject tracked the different force profiles using the two different visual feedback controllers: 1) the measured force and 2) the myoelectric controller. The force profiles were made up of five steps of 1, 2, 3, 4, and 5 N each lasting 2.5 s, arranged in pseudo-random order. A total of three different force profiles were used in the experiment. Each trial consisted of tracking the three force profiles using the two types of visually guided feedback. The subject performed a total of twelve trials. To assess the performance of each trial, the error was calculated between the target force and the response. The performances of both types of controllers were assessed at a 5% significance level.

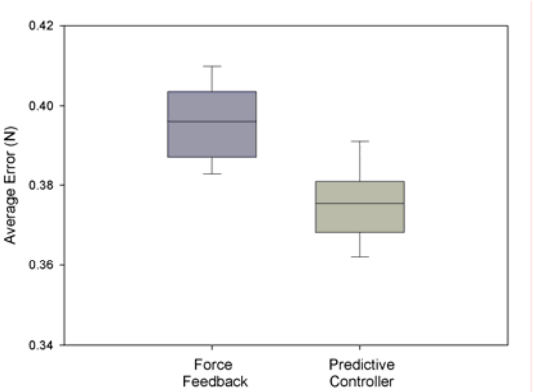

Figure 4: *Performance error boxplots.*

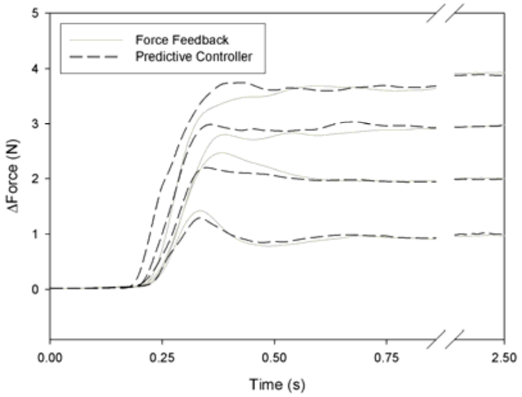

Figure 5: *Average response for both controllers. The response time of the predictive controller is significantly shorter than for the force feedback.*

3. RESULTS

For n = 12 trials, and p = 0.00001, the one-tailed t-test indicates that the performance error using the myoelectric controller was significantly lower than using force feedback (Fig. 4). This result reveals that the myoelectric signals improve the overall tracking response. The myoelectric controller improved the dynamic responses during the time period 190 ms to 1 s after onset of the stimulus, compared to using force feedback. The myoelectric controller provided 14% performance enhancement (p = 0.000002, for a one-tailed t-test) compared to the force feedback control. During static finger forces (1-2.5 s after stimulus onset), there was no significant difference between both controllers (p = 0.78, for a two-tailed t-test). This result suggests that both controllers performed equally well during the stable holding phase of the tracking task.

4. DISCUSSION AND CONCLUSIONS

It was found that the myoelectric-assisted controller enhances the ability to control forces in a visually-guided tracking task. The predictive EMG-based model did not provide significantly more overshoot in the response (Fig. 5). The predictive model merely provides a faster response while being equally capable of providing finer touch control. These results provide evidence that an individual's ability to control a device via a man-machine interface is improved by combining myoelectric signals with mechanical sensors. We believe that an FES system that may require closed-loop force control can be made more accurate and faster in compensating for perturbations by providing similar myoelectric feedback. In particular, such FES system would be able to predict the output force produced by its stimulation by measuring EMG activity and immediately, in real-time, compensating for the error that is expected to occur 50 ms later.

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