SIMULTANEOUS AND PROPORTIONAL ESTIMATION OF MULTIPLE DOFS FOR MYOELECTRIC PROSTHESES: A COMPARISON BETWEEN FORCE AND POSITION CONTROL PARADIGMS

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ABSTRACT

This paper studies the problem of simultaneous and proportional myoelectric control of multiple DOFs for unilateral transradial amputees. Two control strategies namely force and position estimations were investigated. In the first, a force experiment, the subject performed isometric contractions while the force applied by the limb was measured. In the second, a position experiment, limb free movements were permitted during which limb joint angle was recorded. Artificial neural networks (ANN) were trained to estimate force/position from EMG of the contralateral limb during mirrored bilateral contractions. This research used contractions with combined activations of three DOFs including wrist: flexion/extension, radial/ulnar deviation and forearm supination/pronation. In the case of the contralateral limb, force estimation (R^2=0.79±0.03) demonstrated significantly higher performance with respect to position estimation (R^2=0.73±0.04).

INTRODUCTION

There has been a long-standing debate as to whether the human motor system controls kinematics (position) or dynamics (force) related variables. In general, it appears that specific brain regions tend toward dynamics and others toward kinematics, and even within a brain region a neural representation may alter [1].

Current myoelectric prostheses proportionally regulate the velocity of the prostheses movements using the mean absolute value of EMG. However, other strategies have been studied in the literature. Jiang et al. [2] modeled EMG-force relationship in an isometric condition by an ANN at three DOFs of the wrist: flexion/extension, radial deviation/ulnar deviation and forearm supination/pronation. The model was able to predict the force using the measured EMG from the arm even when combinations of DOFs were active. Nielsen et al. [3] improved the performance of the system by including combined activations of DOFs in the training set.

Since it is not possible to measure force from an amputated limb, Jiang et al. [2] proposed a semi-unsupervised method for force estimation. The results of this study were not satisfactory when the third DOF (supination/pronation) was included. To address the case of unilateral amputees, Nielsen et al. [4] trained an ANN using force from the intact limb as the target, during mirrored bilateral contractions. This work however didn’t include the third DOF.

Muceli et al. [5] trained an ANN to model the EMG-kinematics relationship for the same three DOFs during dynamic mirrored bilateral contractions. However, the use of dynamic bilateral contractions for both limbs as in [5,6] is potentially poorly motivated because much of the modulation in EMG with position is due to change in geometry of the muscle through the excursion of joint angle. Amputees are unlikely to produce these geometric changes, especially if the muscle is tethered to the distal bone. An amputee’s situation probably more closely resembles a normally limbed individual producing an isometric contraction against an immovable force. Even in amputees with muscle that is not tied down, the muscle shortens but not against a load; rather it typically retreats with significant movement. This does not resemble the normal shortening with joint movement in a normally limbed individual.

This paper presents ongoing research to make a comparison between force and position control strategies in simultaneous and proportional myoelectric estimation of multiple DOFs for unilateral transradial amputees.

MATERIALS & METHODS

Experimental Protocol

One normally limbed subject with no known neuromuscular disorder (age 30 years) took part in this experiment. Two experiments were conducted in order to make a comparison between force and position control paradigms in three DOFs, i.e. wrist: flexion-extension, radial-ulnar deviation and forearm supination-pronation. Seven bipolar wireless surface electrodes (Delsys Inc. [7]) were placed on each arm, six equally spaced around the forearm, and one on the biceps. EMG data were acquired with a sampling rate of 2000 Hz. Electrodes were not detached throughout the experiment to maintain similar electrode positions for both force and position tests.

In the first, a force experiment, EMG-force mapping in an isometric condition was investigated. During this experiment, the subject sat in a chair with the forearms secured to two armrests. Two handles attached to a steel frame mounted in front of the chair fixed the hands in a neutral position with palms facing inward. A 6-axis force/torque transducer (Gamma FT-130-10, ATI Industries) was mounted between the right handle and the steel frame, so as the x axis corresponded to flexion/extension, y axis to radial/ulnar deviation and z axis to supination/pronation. The analog force was sampled at 1000 Hz using a 12 bit A/D converter. The subject was asked to perform a series of mirrored bilateral contractions as in [2]. During the experiment, the measured force was displayed using a moving 3D pyramid on screen to provide the subject with a visual feedback. EMG from both arms and force from the right limb were recorded simultaneously.

In the second, a position experiment, EMG-position relationship during dynamic contractions was studied. The subject sat in a chair with two armrests holding the arms and performed bilateral dynamic contractions according to Table 1.

Table 1: Position experiment movements

Each trial was 40 s in duration. The experiment consisted of 11 prescribed movements and 2 free run trials.

Prescribed movements trials: Repeating the following movement: Moving from neutral position to maximum contractions of single or combined DOFs, maintaining the maximum contraction for 1 s and returning to zero position and keeping it for 1 s. Transitions times were approximately 1 s. The contractions were: flexion, extension, radial deviation, ulnar deviation, supination, pronation, flexion & supination, flexion & pronation, extension & supination, extension & pronation, radial deviation & supination, radial deviation & pronation, ulnar deviation & supination, ulnar deviation & pronation.

Free run trials: Arbitrary movements involving combinations of DOFs (e.g. maintaining supination while performing sinusoidal contractions of flexion/extension).

The positions of the markers were captured by a Vicon 512 system [8] using 7 infrared video cameras at 60 Hz. Six reflective ball shaped markers were placed on the right arm as in [5]. To synchronize EMG and position data recordings, the Vicon was triggered through PC serial port. During this experiment, EMG from both arms and position from the right limb were recorded concurrently.

Data processing

All data processing was conducted offline. Joint angles for the three DOFs were calculated using the marker position data as described in [5]. The surface EMG data were bandpass filtered (10-900 Hz, eighth order butterworth filter). It has been shown that time domain (TD) features of EMG including mean absolute value, zero crossings, slope signs changes and waveform length contain important neural control information [9]. Using a window length of 100 ms, EMG TD features were calculated. Position and force data were upsampled to pair with EMG features. Multilayer perceptron artificial neural networks (ANN) were used to learn the association between EMG features from each arm and the force (in the first experiment) and position (in the second experiment). All data sets were divided into five blocks (each block containing one fifth of a trial) for a fivefold cross-validation procedure, using one block as the test data and the other four blocks as the training set. The ANNs were trained with the right arm forces/joint angles as targets and EMG features from either the right (ipsilateral) or left (contralateral) arm as inputs to ANNs. A separate ANN for each DOF was employed. Each ANN had one hidden layer of five neurons, with the hidden and output layers having sigmoid and linear activation functions, respectively. The training algorithm was Levenberg-Marquardt back-propagation. The estimation performance for each DOF was evaluated using the coefficient of determination (R^2). The overall performance for all DOFs was calculated by the multivariate R^2 as proposed in [10].

RESULTS

The R^2 values for each DOF as well as the overall performances are listed in Table 2. Figures 1 and 2 illustrate the estimated force and position in three DOFs for the contralateral limb. A one way ANOVA test showed that for the given data set force control paradigm performs significantly better (p=0.02) than position across five test sets.

Table 2: R^2 values for contralateral (ipsilateral) limb in each experiment

	Position	Force
overall	0.73±0.04 (0.72±0.07)	0.79±0.03 (0.83±0.03)
Fle/Ext	0.78±0.04 (0.86±0.03)	0.84±0.05 (0.88±0.04)
Rad/Uln	0.57±0.07 (0.66±0.03)	0.78±0.05 (0.80±0.06)
Sup/Pro	0.72±0.05 (0.65±0.12)	0.70±0.09 (0.78±0.08)

DISCUSSION

The performance on the ipsilateral limb is consistently better than on the contralateral limb (except for sup/pro in position experiment), which is expected and consistent with previous work [4].

It was observed that when free run movements were excluded from the position experiment, estimation performance increased significantly for both ipsilateral and contralateral arms. This reflects the relatively low ability of the position estimation in highly dexterous arm movements.

Since movements in position experiment did not involve pushing against a resistance, the EMG was low especially for smaller contraction angles. This made difficulties for ANNs in position estimation to discriminate between smaller angles. This problem can be considered as a limitation of experimental design which did not provide resistance in movements, and therefore biased the results in favor of force.

A factor that reduced either force or position estimation accuracy was the movement of muscles under skin during contractions especially rotation. This movement was more pronounced during dynamic contractions.

There has not been enough experimental evidence in the literature to answer the question of which muscle variables are controlled by the CNS. Force, length, stiffness, velocity, etc. are some possible answers. However, it seems that more than a single variable is controlled by the CNS [11].

The purpose of this paper was to compare force and position myoelectric control strategies for unilateral transradial amputees. For the given data set, force control demonstrated significantly higher estimation accuracy. The future studies will involve multiple subjects and a different protocol for position experiment which more closely resembles an amputee's case.

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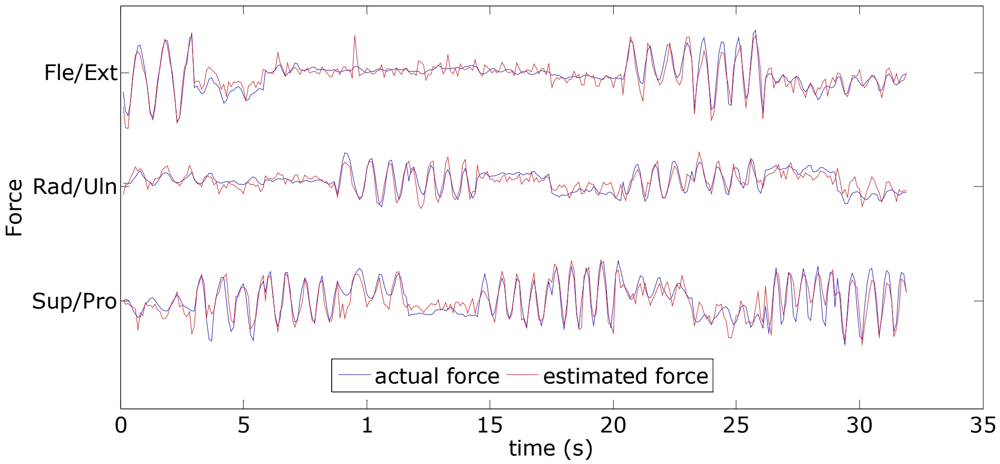

Figure 1: Force experiment: An example of contralateral limb force estimation

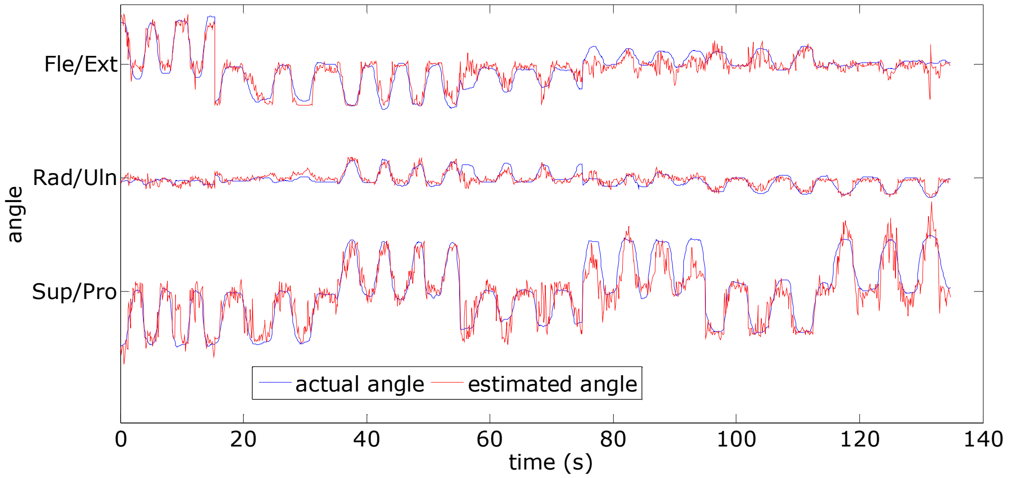

Figure 2: Position experiment: An example of contralateral limb angle estimation

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