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Assessment of a Multigrasp Myoelectric Control Approach for use by Transhumeral Amputees

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Abstract— **The authors have previously developed a multigrasp myoelectric controller, and assessed the ability of healthy subjects to control the configuration of a multigrasp hand prosthesis using musculature on the anterior and posterior aspects of the forearm, as would be representative of controller use by a transradial amputee population. In this paper, the authors conduct a similar study, this time to assess the capability of a transhumeral amputee to control a multigrasp hand from residual musculature on the upper arm. Specifically, experiments are conducted on five healthy subjects, comparing their ability to obtain one of seven hand postures in a virtual prosthesis from EMG measurement of the respective biceps and triceps musculature. The ability to control the virtual hand prosthesis is compared with their ability to do so with their intact hand, as measured by a dataglove. Results indicate an average transition time using the EMG controller on the biceps and triceps of 1.86 seconds, relative to 0.82 seconds with the dataglove.**

I. Introduction

As of 2005, there were approximately 41,000 persons living in the United States with major (i.e., excluding loss of fingers) upper limb amputations [1]. Extrapolating from a recent sampling of amputees [2], the two most common levels of major upper limb amputation are the transradial and transhumeral levels, each of which constitute approximately one third of the total upper extremity amputee population. After suffering limb loss, upper extremity amputees generally have two options in prosthesis types for functional replacement of the hand, which are either a body-powered or a myoelectric type. A highly constraining factor in both types of prostheses is the limited number of control inputs with which the user can control the hand prosthesis (or terminal device). Specifically, whether the control input is a body-powered cable or a myoelectric signal, hand prostheses have traditionally been limited to a single control channel, which is typically used to open and close either a split hook (in the body-powered case) or a single degree-of-freedom hand (in the myoelectric case).

Recent technological advances (i.e., the power density of rare-earth magnet brushless motors, the energy density of light metal batteries, the enhanced computational capability of microcontrollers, etc.) have brought to the near horizon the possibility of multigrasp hand prostheses, which are able to provide to the amputee a number of hand postures and grasps. For a recent survey of several emerging multigrasp prostheses, see [3]. Despite the emergence of such devices, the enhanced functionality they offer is not useful to the amputee without a multigrasp control interface that offers intuitive, effective, and reliable access to the multiple grasps and postures they can provide.

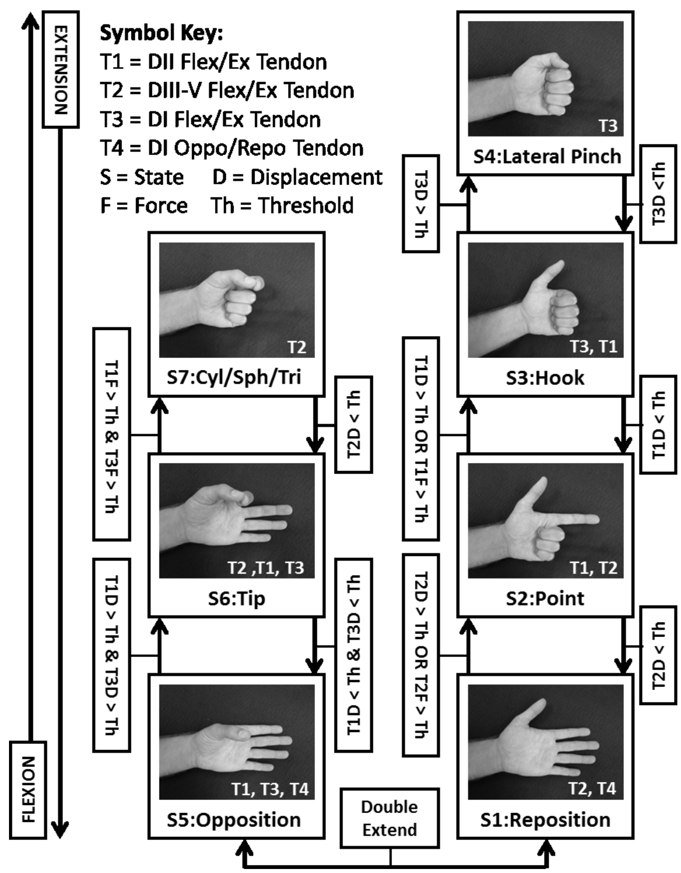

Figure 1. The Multigrasp Myoelectric Control State Chart.

A number of approaches to multigrasp prosthesis control, based on the measurement of surface electromyogram (EMG) as the primary control signal, have been proposed. These fall largely into two categories, which are pattern recognition approaches (e.g., see [4-7]), and hierarchical approaches (e.g., see [8-13]). The authors have developed and previously published a hierarchical multigrasp hand prosthesis control approach, called Multigrasp Myoelectric Control (MMC) [14]. In that paper, the authors focused on the ability of a transradial amputee to control a multigrasp hand prosthesis via two surface EMG electrodes, one on the anterior and posterior aspects, respectively, of the user's forearm. Note, again, that transradial amputees constitute approximately one third of the total upper extremity amputee population.

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In this paper, the authors conduct a similar study, but instead of focusing on the efficacy of the approach for transradial amputees, the authors focus on the efficacy of the approach for transhumeral amputees. As previously mentioned, like the transradial amputee population, the transhumeral amputee population constitutes approximately one third of the total upper extremity amputee population. The control method is similar for both populations, although rather than utilizing one electrode site on each of the anterior and posterior aspects of the forearm, respectively, as is the case for transradial amputees, a transhumeral amputee will utilize surface EMG sites on the biceps and triceps muscles, respectively. Such musculature is obviously further removed from operation of the native hand, and thus the authors intent in conducting this study was to assess the extent to which EMG of the upper arm musculature provided effective control of a multigrasp prosthesis. As such, in this paper, the authors present the results of a study (on five healthy subjects) indicating the ability to control a multigrasp prosthesis from the upper arm, and compare those results to the capability to do the same with the native hand, and to the capability to control from electrode sites on the forearm.

II. Multigrasp Myoelectric Control

The MMC method involves an event driven finite-state machine that transitions between a finite set of fixed postures (states), where the future state of the prosthesis is determined by the current state and electromyogram (EMG) input to the state machine. This structure is illustrated in Fig. 1. In this work, the MMC control method was modified to better address transhumeral amputations. That is, musculature on the upper arm, as opposed to the lower arm, has been utilized. Specifically, contraction of the biceps muscle (flexion) is associated with upward movement in the state chart, while contraction of the triceps muscle (extension) is associated with downward movement in the state chart. Furthermore, the co-contraction event has been replaced with a double extension action to transition between the opposition and reposition states (which are associated with movement of the thumb). The double extension consists of fully extending the prosthesis within the opposition (or reposition) state, relaxing, and extending again to initiate automatic reposition (or opposition) of the thumb. To this end, the muscle relaxation time has been accounted for in this implementation by determining the relaxation period for each subject during the signal conditioning process. This preserves co-contraction for possible multiplexing between hand and elbow functions, and eliminates the necessity of performing co-contraction during hand motions.

III. Methods

Five non-amputee volunteers, aged 20-30 years, participated in this study. Each volunteer underwent six trials which involved controlling a virtual prosthesis to achieve a series of randomized target postures. In the first six trials, this was done using a dataglove to capture the motion of the native hand. This was followed by six other trials where the MMC was used to control the virtual prosthesis through a similar set of random postures. In this way, the performance of the MMC could be compared to that of the native hand. The time between an individual subject's trials ranged from one to four days with an overall experimental completion period of forty five days. This study was approved by the Vanderbilt University Internal Review Board.

A. Virtual Prosthesis

The virtual prosthesis model developed in [14] was implemented in this study to evaluate the performance of the native hand and the MMC. This model uses a virtual prosthesis which is displayed on a computer screen and controlled by the subject using either the native hand (via a dataglove) or by MMC (via EMG). A virtual ghost (an overlaid duplicate of the virtual prosthesis) is used to display target postures for the user to acquire with the virtual prosthesis.

B. Dataglove

In order to evaluate the ability of the native hand to obtain preset postures with the virtual prosthesis, a dataglove was used to obtain temporal and spatial data for later comparison with MMC. Specifically, the dataglove captured flexion/extension of the index and middle fingers, as well as flexion/extension and opposition/reposition of the thumb, using variable resistance bend sensors. In the virtual prosthesis, motion of the ring and little fingers was coupled to that of the middle finger, allowing the achievement of all target postures. Dataglove details may be found in [14].

C. EMG

To obtain surface EMG data, two Ag/AgCl electrodes (Myotronics, Inc.) were affixed to the subject's skin after each EMG site was sanitized with alcohol pads. The electrodes were positioned over the subject's biceps and triceps muscle bellies (in parallel to the muscle fibers) with a reference electrode positioned proximal to the elbow. These positions were marked for consistent placement between subsequent trials. The output signals of the electrodes were then preamplified (K=100) and low pass filtered (f_c = 500 Hz) near the electrode sites using custom analog circuitry. The signals were then passed to Simulink Real Time Windows Target using a Humusoft MF624 data acquisition card where they were digitally high-pass filtered (f_c = 50 Hz) and rectified. The signals were then digitally low-pass filtered (f_c=5hz) to obtain velocity references for the MMC.

IV. Experimental Procedure

As mentioned above, each trial consisted of achieving random sequences of target postures. The target postures coincide with the MMC states (reposition, point, hook, lateral pinch, opposition, tip and cylindrical). When a new target posture is displayed, the subject manipulates the virtual prosthesis using either the dataglove or the MMC. For the dataglove this manipulation consists of movement of the native hand. For the MMC this consists of isometric contraction of the biceps or triceps muscle (where the subject grasps a rigid handle to isolate movement of the arm). When the virtual prosthesis closely matches the target posture (±25% range of motion) the virtual ghost disappears indicating that the target posture has been achieved. To be considered successful, a target posture must be held for 3 seconds. A new target posture is displayed after successfully achieving a target posture, or if the target posture is not achieved within five seconds. If five seconds pass without achievement of the target posture the transition is considered a failure, and a new posture is displayed. The time it takes for the subject to achieve a target posture is recorded and defined in this study to be the *transition time*. The percentage of successful target postures achieved in less than five seconds is defined in this study to be the *transition completion rate.* Note that the transition times in this study are influenced by intrinsic biological factors such as visual, cognitive, neural, and muscular delays.

Each subject was given a period of up to 15 minutes to get accustomed to the operation of the dataglove and MMC before performing the experimental trials. Each trial lasted approximately 10 minutes. Note that there are a total of 42 possible transitions among the MMC states (i.e., from any of the seven states, there are six other possible states to which the user can transition). During a trial, each transition type is presented three times, resulting in a total of 126 transitions, with each posture appearing 18 times.

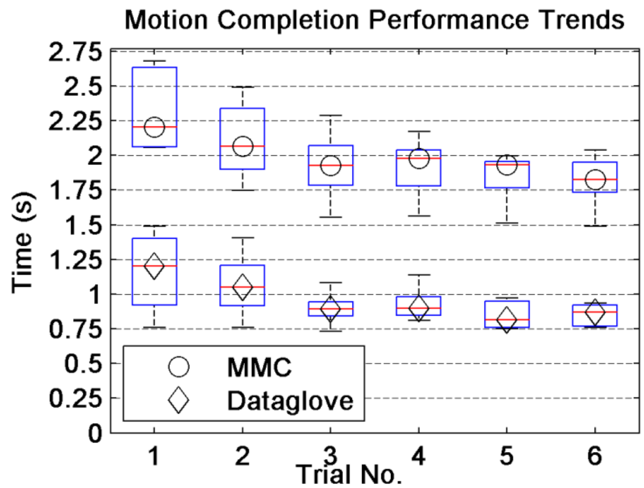

Figure. 2. Median motion completion times for each trial, where each box encompasses the 25th to 75th percentiles for that trial and control method. Whiskers extend to the minimum and maximum recorded times.

V. Results and Discussion

A. *Performance Trends*

From Fig. 2 it can be seen that, in general, median transition times decreased with subsequent trials. This trend is presumably a result of subject learning over time. After the third trial, the median transition times for both the data glove and the MMC fell within 10% of their respective means, indicating decreased improvement and minimal gain in the repetition of trials. For this reason, the final three trials were used to compile the data reported herein.

B. *Transition Time*

The average transition times for the data glove (native hand) and the MMC (EMG) trials for each transition type are shown in Tables I and II, respectively. The standard deviations are noted in parentheses. The average overall transition times (the average time to go from any one posture, to any other) for the data glove and the MMC were 0.82 seconds (standard deviation of 0.23 seconds) and 1.86 seconds (standard deviation of 0.75 seconds). The difference in these times may be attributed to two primary factors. First, the topography of the state chart dictates that the transition time between postures will be proportional to the distance between them (see Fig. 1.). Second, transitions which require opposition or reposition of the thumb (and therefore the performance of the double extend action) will necessarily incorporate the muscle relaxation time of the subject, and increase transition times accordingly. Also, variations in relaxation time from subject to subject will lead to increased deviation in transition times for the MMC. In these experiments, the average muscle relaxation time was found to be 0.50 seconds, with a standard deviation of 0.25 seconds. The average overall transition times and relaxation times for each subject may be found in Table III.

TABLE I. Average Transition Times For All Subjects Using the Native Hand (Dataglove)

		Target Posture						
		Lateral	***Hook***	***Point***	***Reposition***	***Opposition***	***Tip***	***Cylindrical***
Original Posture	***Lateral***		0.59 (0.26)	0.65 (0.22)	0.68 (0.22)	0.84 (0.50)	1.12 (0.73)	0.82 (0.69)
	Hook	0.55 (0.18)		0.60 (0.18)	0.68 (0.38)	0.89 (0.50)	1.20 (0.73)	0.73 (0.38)
	Point	1.70 (0.34)	0.51 (0.16)		0.65 (0.19)	0.78 (0.29)	1.25 (0.73)	0.83 (0.38)
	Reposition	0.87 (0.32)	0.59 (0.23)	0.73 (0.32)		0.64 (0.28)	1.13 (0.73)	0.85 (0.39)
	Opposition	0.75 (0.27)	0.81 (0.38)	0.82 (0.34)	0.62 (0.25)		1.12 (0.73)	1.13 (0.45)
	Tip	0.72 (0.22)	0.69 (0.39)	0.71 (0.22)	0.79 (0.38)	0.81 (0.30)		0.90 (0.50)
	Cylindrical	0.69 (0.26)	0.72 (0.42)	0.67 (0.25)	0.69 (0.23)	0.96 (0.58)	1.08 (0.73)	

TABLE II Average Transition Times For All Subjects Using MMC (EMG)

		Target Posture						
		Lateral	***Hook***	***Point***	***Reposition***	***Opposition***	***Tip***	***Cylindrical***
Original Posture	***Lateral***		1.07 (0.43)	1.31 (0.63)	1.24 (0.19)	1.89 (0.31)	2.65 (0.66)	2.93 (0.52)
	Hook	0.83 (0.20)		0.98 (0.31)	1.04 (0.24)	1.71 (0.45)	2.39 (0.59)	2.63 (0.45)
	Point	2.23 (0.97)	0.99 (0.29)		0.73 (0.2)	1.46 (0.4)	2.23 (0.55)	2.65 (0.62)
	Reposition	1.71 (0.55)	1.42 (0.28)	1.31 (0.44)		1.57 (0.64)	2.34 (0.49)	2.50 (0.40)
	Opposition	3.00 (0.52)	2.91 (0.62)	2.51 (0.53)	1.52 (0.45)		1.24 (0.64)	1.31 (0.25)
	Tip	2.87 (0.56)	2.84 (0.74)	2.42 (0.50)	1.60 (0.43)	0.63 (0.16)		0.98 (0.34)
	Cylindrical	3.10 (0.64)	2.89 (0.48)	2.60 (0.45)	1.63 (0.18)	1.71 (0.28)	1.02 (0.35)	

In a previous study, which investigated the use of MMC for transradial amputees [14], the data glove and MMC transition times were found to be 0.81 seconds (standard deviation of 0.14 seconds) and 1.49 seconds (standard deviation of 0.15 seconds). Note that the transition times in the previous study do not include muscle relaxation time because muscle relaxation (double extension) was not required to transition among the opposition and reposition states. Note, furthermore, that 24 of the 42 transitions in the state chart require opposition or reposition, while 18 of the 42 transitions do not. Therefore, the results of the previous study can be adjusted to arrive at a theoretical estimate of the average overall transition time, if double extension had been utilized, by adding the average muscle relaxation time to the 24 transitions which require opposition or reposition. This is illustrated in the equation (1) below:

$$\left[(1.49\ s)\left(\frac{18}{42}\right)\right] + \left[(1.49\ s + 0.50\ s)\left(\frac{24}{42}\right)\right] = 1.78 \quad (1)$$

By doing this, it can be seen that the transition times reported in the previous and current study are comparable. Specifically, data glove transition times for the previous and current study were 0.81 and 0.82 seconds, respectively. The MMC transition times for the previous and current study were 1.78 (as adjusted to reflect the use of double extension) and 1.82 seconds, respectively.

C. *Transition Completion Rate*

The transition completion rates for the data glove and the MMC in this study were found to be 99.2% and 99.3%, respectively. These results indicate that the reported transition times are accurate regardless of whether or not the 5 second cutoff time is considered. These results are also consistent with the transition completion rates reported in [14], indicating that MMC control is dependable at both the transhumeral and transradial level.

TABLE III. AVERAGE TRANSITION TIME AND RELAXATION TIME FOR EACH SUBJECT USING MMC

Subject	Transition Times (seconds)	Relaxation Times (seconds)
HS 1	1.94	0.70
HS 2	1.92	0.38
HS 3	1.84	0.54
HS 4	1.52	0.49
HS 5	2.10	0.41
Average	1.86	0.50

VI. CONCLUSION

This paper presents a version of a previously published multigrasp myoelectric controller which has been modified for use by transhumeral amputees, and investigates the ability of a person to control a multigrasp hand prosthesis from musculature in the upper arm (i.e., from the biceps and triceps muscles). Also, the MMC approach used in this paper utilized double extension to transition between the opposition and reposition states, preserving co-contraction for the future development of multifunction prostheses. The study of five healthy subjects indicates that on average the subjects were able to control the multigrasp capability of the virtual prosthesis using musculature in the upper arm essentially as well as subjects in a previous study were able to control the prosthesis with the musculature in their forearm. The study therefore indicates that the use of the MMC method should apply equally as well to either the transradial or transhumeral levels of amputation.

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