34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

Preliminary Functional Assessment of a Multigrasp Myoelectric Prosthesis

Skyler A. Dalley, *Student Member, IEEE,* Daniel A. Bennett, *Student Member, IEEE,* and Michael Goldfarb, *Member, IEEE*

Abstract—**The authors have previously described a multigrasp hand prosthesis prototype, and a two-site surface EMG based multigrasp control interface for its control. In this paper, the authors present a preliminary assessment of the efficacy of the prosthesis and multigrasp controller in performing tasks requiring interaction and manipulation. The authors use as a performance measure the Southampton Hand Assessment Procedure (SHAP), which entails manipulation of various objects designed to emulate activities of daily living, and provides a set of scores that indicate level of functionality in various types of hand function. In this preliminary assessment, a single non-amputee subject performed the SHAP while wearing the multigrasp prosthesis via an able-bodied adaptor. The results from this testing are presented, and compared to recently published SHAP results obtained with commercially available single-grasp and multigrasp prosthetic hands.**

I. Introduction

Functional hand prostheses have traditionally been limited to single-degree-of-freedom devices. In contrast, the human hand is extensively articulated, possessing approximately twenty major degrees of freedom which allow it to execute a wide variety of grasps and postures. The associated disparity in performance and appearance between the human hand and these traditional replacements is evidenced by surveys which indicate that greater functionality [2] and increased articulation [3] are among top design priorities for amputees. Recently, several multigrasp prosthetic hands have begun to emerge in both academic research and commercial trade. A recent review of such hands is given in [4]. Relative to single-grasp hands, these devices have enhanced potential to restore normal biomechanical function and capability. However, the full realization of this potential requires the development of an effective multigrasp control interface, which enables the user to access the capability of the multigrasp prosthetic hand in an intuitive, reliable, and robust manner. (For a review of multigrasp control methods to date, the reader is referred to [5-10] and [11-14].) In prior work [15], the authors described a surface-EMG-based multigrasp myoelectric controller (MMC), which enables attainment of three hand postures and six hand grasps. To assess the efficacy of the MMC with respect to controlling hand posture, experiments were conducted which characterized the ability of (non-amputee) subjects to command the motion of a virtual prosthesis through random sequences of target postures using both their native hand (via a Dataglove) and the MMC (via EMG). These experiments indicated that the MMC enabled subjects to effectively obtain target postures within a virtual environment. Although these results were promising, controlling a virtual prosthesis to obtain various postures is quite different from using a physical device to conduct the activities of daily living (ADLs). Specifically, the ADLs require interaction with the environment. Such interaction is associated with movement and loads that can potentially affect the myoelectric interface used for the MMC. Further, the ADLs require object manipulation, which was not represented in the virtual prosthesis studies. Thus, while the virtual studies provided important data with respect to the value and potential efficacy of the MMC approach, they were insufficient to indicate the robustness of the interface and to characterize the ability to interact with the environment using the MMC method (i.e., efficacy in a virtual environment is necessary for an effective multigrasp control approach, but not sufficient to indicate the efficacy of performing the activities of daily living with a physical device using that approach).

This paper describes a preliminary assessment of the ability to perform the activities of daily living while using the MMC to control a multigrasp prosthesis. The aim of this work is to: present a preliminary characterization of the efficacy of the prosthesis during manipulation, capture in the characterization physical interaction with the environment, and demonstrate interdependence between the hand and affected limb. To provide a validated framework for such an assessment, the authors utilize the Southampton Hand Assessment Procedure, or SHAP [16]. The SHAP consists of a series of tasks that entail manipulation of various abstract objects and the performance of other various tasks that are representative of common activities of daily living (ADL's). The assessment procedure has been shown to be a statistically reliable measure of hand functionality, and has been used recently to assess the functionality of multigrasp and single-grasp myoelectric prostheses [1]. In the preliminary assessment described here, the authors present the SHAP results from a healthy subject, wearing the Vanderbilt Multigrasp (VMG) hand prosthesis prototype via an able-bodied adaptor. The VMG prosthesis prototype, MMC controller, and experimental procedure are described in Section II, while the results of the assessment are presented and compared to those published previously in Section III.

*This work was supported in part by the National Institutes of Health under Grant 1R21 HD068753-01.

S. A. Dalley, D. A. Bennett and M. Goldfarb are with the Department of Mechanical Engineering, Vanderbilt University, Nashville, TN 37240 USA (e-mail: skyler.a.dalley@gmail.com; daniel.a.bennett@vanderbilt.edu, michael.goldfarb@vanderbilt.edu; phone: 615-343-6925; fax; 615-343-6924).

II. METHODS

A. Prosthetic Hardware

The Vanderbilt Multigrasp Hand utilized for the assessment reported in this paper possesses 4 degrees of actuation (DoA), which drive 9 degrees of freedom (DoF). Movement of the hand is caused by the action of polyethylene tendons, which spool onto pulleys affixed to the shafts of Brushless DC motors. This actuation scheme (illustrated in Fig. 1) allows for active flexion and extension as well as active opposition and reposition of the first digit (thumb) about the carpometacarpal joint (2 DoF, 2 DoA), active flexion and extension of the second digit (index finger) about the metacarpophalangeal joint (1 DoF, 1 DoA), and active flexion of digits III-V (middle, ring, and little fingers) about their metacarpophalangeal and proximal interphalangeal joints (6 DoF, 1DoA). Passive torsion springs provide extension of digits III-V. To perform the assessment, the VMG hand was mounted on an able bodied adapter, as displayed in Fig. 2. The able bodied adapter also allowed for passive pronation and supination of the wrist.

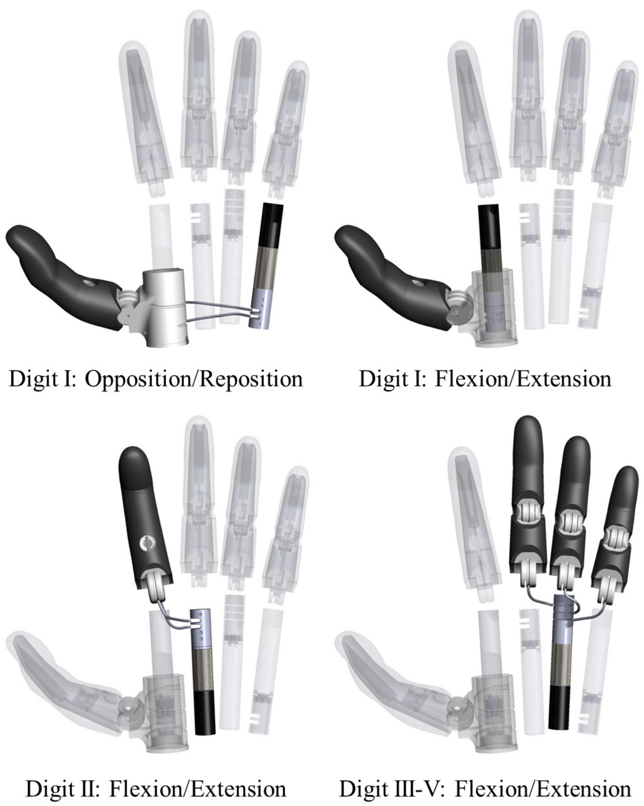

Figure 1. Actuation scheme of the Vanderbilt Multigrasp Hand.

B. Control Methods

The MMC (see Fig 3.) consists of an event-driven, finite-state controller which interprets high-level commands issued by the user to coordinate the motion of a multigrasp prosthesis using a standard, two-site myoelectric interface. Specifically, by contraction of the forearm flexors and extensors (located on the anterior and posterior aspects of the forearm, respectively), the user may determine whether the hand

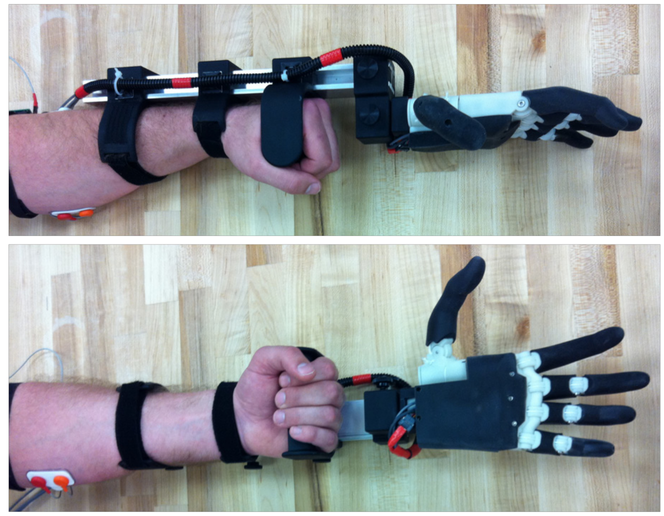

Figure 2. The able-bodied adapter and Vanderbilt Multigrasp Hand. EMG electrodes are located on the proximal forearm.

closes or opens. Depending on the initial position of the thumb, closing of the hand (caused by flexion) proceeds continuously through either the Reposition (Platform), Point, Hook, and Lateral Pinch postures (states) or the Opposition, Tip, and combined Cylindrical, Spherical, and Tripod postures (states). Opening of the hand (caused by extension) reverses these sequences. State transitions occur based on predefined tendon displacement or force thresholds.

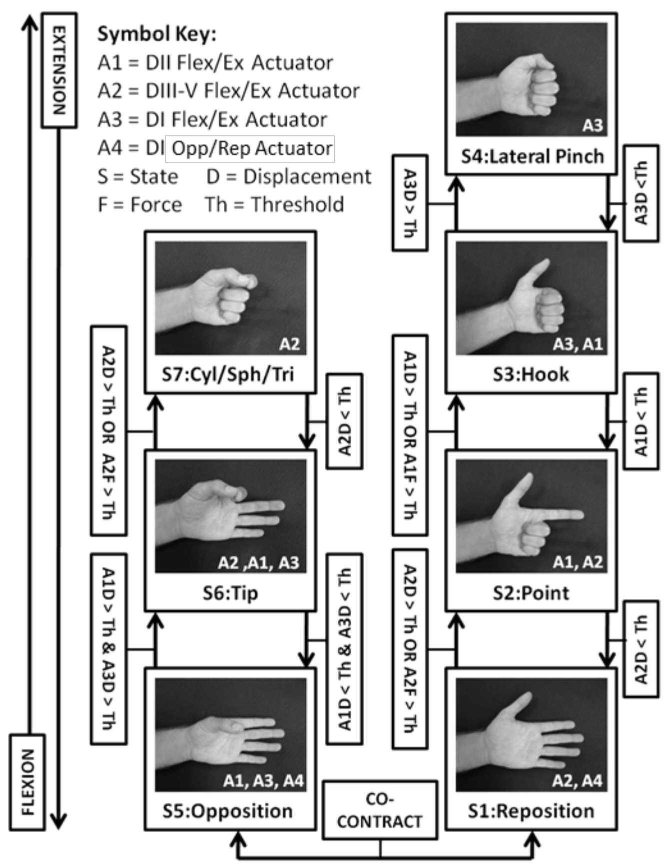

Figure 3. Structure of the Multigrasp Myoelecric Controller (MMC).

To switch between the opposition and reposition states (and thereby determine the position of the thumb), the user may either co-contract the forearm musculature or perform extension after the hand has fully opened in either the opposition and reposition states. Grasping occurs by virtue of movement among the states. The magnitude of the contraction dictates either the speed of movement (if moving in space) or magnitude of force (if grasping an object). For a detailed description of the MMC controller, the reader is referred to [15].

C. SHAP Functional Hand Assessment

The SHAP is comprised of tasks which require the manipulation of 12 abstract objects and the performance of 14 activities of daily living (ADLS), all of which require use of the spherical, tripod, power, lateral, tip and extension grasps. The ADLS utilized in the SHAP consist of: picking up coins, undoing buttons, cutting food, turning pages, removing a jar lid, pouring from a glass measuring cup, pouring from a carton, lifting a heavy jar, lifting a light can, lifting a tray, rotating a key, opening/closing a zipper, rotating a screw, and using a door handle. The tasks are self timed by the participant. The nominal score for a SHAP test is 100 (typical hand functionality) with lesser scores indicating degree of impairment and greater scores indicating exceptional performance. Because the SHAP is based on basic prehensile forms, impairment within a specific grasp or posture may also be determined [16]. In the work described here, a non-amputee subject who was familiar with the MMC control methodology performed the SHAP test with the VMG Hand. The prosthesis was attached to the subject's forearm using an able-bodied adapter. As it was the subject's first experience utilizing this prosthetic hardware to perform the SHAP test, the subject was allowed to rehearse each task until the appropriate strategy could be reliably reproduced. To establish an upper bound on performance, the tasks were then repeated until the time required for each settled, and significant improvement ceased.

III. Results & Discussion

Figure 4 shows the VMG hand performing various SHAP tasks involving abstract objects, and illustrates its ability to adopt the grasps appropriate during them.

As detailed in Table I, the SHAP index of function for the VMG hand and MMC controller was 87, with a functionality profile range of 74 to 91. It was noted that the activities of daily living which required the use of a tool were particularly challenging as it was difficult for the subject to both pick up the tool and position it for use using the prosthesis alone. Because of this, the subject was allowed to use their contralateral hand to assist in initially picking up the instrument and positioning it in the prosthesis at the beginning of the food cutting and screw driving tasks. The SHAP assessment also made evident the importance of the wrist in performing the activities of daily living. In some instances the subject utilized torso movement to compensate for the lack of wrist articulation.

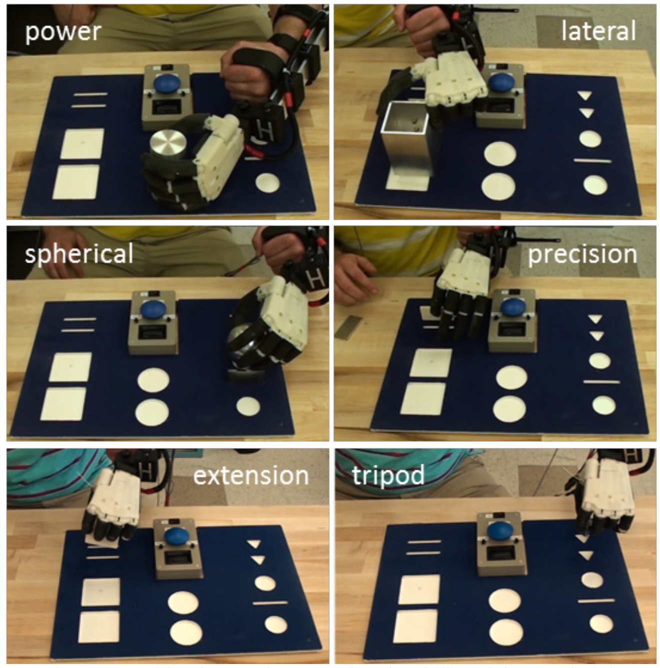

Figure 4. Video frames demonsrating the ability of the Vanderbilt Multigrasp Hand to adopt appropriate grasps during the Southampton Hand Assessment Procedure using the Multigrasp Myoelectric Controller.

To provide context for the results presented here for the VMG Hand and MMC method, the results of [1] are included in the discussion below and in Table I. In that work ([1]) the SHAP performance of a single grasp hand and a multigrasp hand were presented and compared in a case study of a 45 year old male amputee.

TABLE I. SHAP Test Results and Comparison to Contemporary single and multigrasp commercial Prostheses

Functionality Profile	**DMC [1]**	**i-LIMB [1]**	**VMG & MMC**
Spherical	90	90	88
Tripod	76	32	86
Power	75	51	74
Lateral	69	23	83
Tip	39	42	91
Extension	81	55	81
Index of Function	74	52	87

A. VMG with MMC as compared to a Single-Grasp Hand

In [1] SHAP results are provided for the DMC Hand (Otto Bock), a commercially available two-joint, single degree-of-freedom prosthetic device driven by a single motor. In this device the thumb is constantly opposed to the index and middle fingers. The joints of the DMC hand may be opened and closed simultaneously to perform a single grasp. The MMC controller and VMG prosthesis hardware tested in this work showed significant improvement (where, for the sake of discussion, a difference of 10% has been considered significant) in the Tripod (13% increase), Lateral (20% increase), and Tip (130% increase) grasps relative to the DMC

Hand as reported in [1]. In the remaining categories (Spherical, Power, and Extension) performance was similar. Note also that the grasp patterns employed during a SHAP test with the VMG hand are consistent with those of the native hand and so presumably maintain greater fidelity with regard to natural motion. This stands in contrast to single grasp devices, in which the same grasp must be utilized to perform all tasks.

B. VMG with MMC as Compared to a Multiple Grasp Hand

In [1] SHAP results are also provided for the i-Limb Hand (Touch Bionics), a commercially available prosthetic device which possesses 11 joints and 11 degrees of freedom, driven by five DC motors. This device has digits with multiple articulations (including a thumb which may be passively adjusted in opposition and reposition) and is capable of multiple grasps and postures. Relative to the i-Limb hand as reported in [1], the controller and prosthetic hardware tested in this work showed significant improvement in almost every category of the functional profile. Specifically, improvements were seen in the Tripod (170% increase), Power (45% increase), Lateral (20 % increase), Tip (120 % increase), and Extension (47 % increase) grasps. Performance for the Spherical grasp was the same.

C. Comparison Summary

All prosthetic hands compared in this study performed similarly with regard to the spherical grasp. For both the i-Limb and DMC hands it can be seen that the highest scores for each essentially involve whole-hand (spherical, power and extension) grasps (with the exception of the tripod grasp for the DMC hand, which scored 76 versus 75 for the power grasp). In contrast, the highest scores for the VMG hand (with the exception of the spherical grasp) involved precision (tripod, lateral, and tip) grasps. The average precision scores for the DMC, i-Limb, and VMG hands were 61, 32, and 87, respectively. The average whole hand scores for the DMC, i-Limb, and VMG hands were 82, 65, and 81, respectively.

IV. Conclusion

This paper presents a preliminary functional assessment of a multigrasp hand prosthesis and myoelectric controller using the Southampton Hand Assessment Procedure. The procedure was performed by a non-amputee subject using an able-bodied adapter. While the Multigrasp Myoelectric Control method had previously been assessed in a virtual environment to determine its ability to provide timely access to several grasps and postures, the functional assessment described herein provides evidence that the method may be used dependably in conjunction with a multigrasp device to interact with the physical environment as well, enabling the enhanced performance of basic manipulation tasks and the activities of daily living in a manner consistent with the native hand. Specifically, the results of the assessment indicate that the prosthetic system (VMG Hand with MMC) is capable of providing 87% of the functionality typically exhibited while performing the same set of tasks with an intact hand. These results compare favorably to those reported for currently available single and multigrasp myoelectric hands. Future work will involve assessment of the VMG hand and MMC method as used by multiple amputee subjects.

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