Development of Quality of Use Monitor for Upper Extremity Prostheses

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INTRODUCTION

Previous researchers have reported on the high rate of abandonment of upper limb prosthetic devices.(E. A. Biddiss & Chau, 2007, 2008; E. Biddiss & Chau, 2007; Davidson, 2002; Dudkiewicz, Gabrielov, Seiv-Ner, Zelig, & Heim, 2004; Fraser, 1998; Raichle et al., 2008; Silcox, Rooks, Vogel, & Fleming, 1993; Wright, Hagan, & Wood, 1995) Anecdotally, some of our patients report that although they own one or more devices, they do not actually use them in their everyday activities. Others report that their devices remain in the closet because the hassle of donning and doffing them and the discomfort of wearing them outweigh the functional gains that they provide.

Clearly, the ability to objectively measure upper limb prosthetic use during normal living conditions would be beneficial in evaluating the "value" of a prosthetic device and its acceptability. Such a metric would facilitate research comparing home usage of differing types of devices. Subjects may use more than one type of terminal device. A terminal device may take the form of a prosthetic hand, hook, or can be designed for a specific activity. A key aspect of the proposed Take Home Study of an Advanced Prosthetic Device will be assessment of the extent of home usage of the DEKA Arm as compared to home usage of participant's existing prostheses. Although usage of the DEKA Arm can be evaluated through downloadable engineering logs, no similar method is available to assess the extent of conventional upper limb prosthetic use. Further, no prosthesis or special device is available to measure non-manipulative tasks. We believe that designing a method to monitor upper prosthetic limb use would be of great value in understanding the high rates of abandonment. In addition, and perhaps equally important, such sensor systems can also provide a means to objectively assess and compare the functionality of different upper limb prosthetic devices, especially for those that are claimed to be an improvement over existing devices.

The number of patients with upper extremity amputation who are cared for in Veterans Administration facilities is increasing as a result of injuries sustained in recent conflicts. The majority of these amputees will separate from active duty and enroll in VA healthcare. Returning these amputees to full participation in work, leisure and social activities will be challenging given the limitations of commercially available upper limb prosthetics. Historically, upper extremity prostheses have not been well accepted. The literature reports that the rejection rate of upper extremity prostheses is between 19% to 65%.(E. A. Biddiss & Chau, 2007; Davidson, 2002; Dudkiewicz et al., 2004) Further, upper extremity amputees are at increased risk for injuries to the contralateral arm.(Datta, Selvarajah, & Davey, 2004; Jones & Davidson, 1999) Finally, the level of amputation impacts use, with decreasing prosthetic use(Fraser, 1998) and higher rates of rejection(E. Biddiss & Chau, 2007) for persons with more proximal amputations.

Clinical laboratory testing provides important information about the capabilities of prosthesis users, however it does not address how or when they choose to use their prosthesis. A subject is more likely to use the prosthesis during testing than in the community. Prosthetic use has largely been captured by the use of self-report surveys, typically measured in terms of wear time, i.e. how many hours per day or days per week an amputee uses or wears their device. Measurement of prosthetic wear time and usage has also been done by use of a daily diary. Both surveys and daily diary measures require patient recall, and could be filled out by a surrogate. While wear time is an important measure, wear time does not necessarily equate with usage.

One potential measure of prosthetic use is the measurement of grasp frequency. Although this measure may identify active usage of the terminal device, it may not capture all aspects of prosthetic usage. According to Davidson, 30% of prosthetic users reported not using the grasping features at all.(J. Davidson, 2002) Also, grasping activation does not discriminate between multiple attempts to grasp one object or grasping multiple objects. Thus, we believe that capturing the full spectrum of upper extremity prosthesis use would require three measurements; wear time, active extremity use, and grasping activation. We propose to develop a device that will record all three of these elements.

METHODS

Reaching and Upper Extremity Movement

To measure arm movement, we used a single inertial sensor (OPAL, ADPM, Portland, Oregon). The opal sensor contains a three axes accelerometer, three axes gyroscope, and three axes magnetometer. We tested laboratory personnel under two experimental conditions. The first condition was walking around the lab with while the subject was requested to prevent deliberate arm motion; the second condition while standing stationary, reaching for an object on a laboratory shelf. Motion from each axis of the three axis accelerometer was summed. To differentiate between walking and reaching, a threshold was determined by visual analysis (Figure 1). No effort was made to optimize the filter or threshold used. Subsequently, an uncontrolled three hour period was monitoring use of a single subject.

Grasp Detection

Two contacts were attached to a body powered prosthesis used in the laboratory for testing. The contacts were then connected to an electronic counter. With this device, we were able to confirm that we would be able monitor grasp on body powered hooks (Figure 2). The prosthesis was activated 25 times and the results tabulated. It has previously been demonstrated that activation count can be captured from a myoelectric prosthesis (Denaro, Schoenberg, Self, & Bagley, 2001), thus only the body powered was tested, although both methods will be available in the final device.

Mapping Activity to Quality of Use

The group worked to develop a protocol of how to evaluate the combined movements based on movements identified in the Assessment of Capacity of Myoelectric Control (ACMC). (Hermansson, Bodin, & Eliasson, 2006; Hermansson, Fisher, Bernspång, & Eliasson, 2005) The team then identified which movements could be mapped to data from the upper extremity monitor sensing elements. The ACMC is currently rated by evaluation from a certified physical or occupational therapist. Movements from the ACMC were categorized based on how they could be measured using the activity monitor. Components include grasping, holding, releasing with and without stabilization, movement, and visual feedback.

RESULTS

Reaching and Upper Extremity Movement

The data showed that reaching and upper extremity movements could be discriminated from whole body movement using a single inertial sensor. Figure one demonstrated that the measurements from the inertial sensor are of an order of magnitude larger for a reaching arm movement when compared to walking and standing.

Based on this preliminary data, we are confident that an inertial sensor will be appropriate to detect 1) wear time, and 2) active prosthetic use.

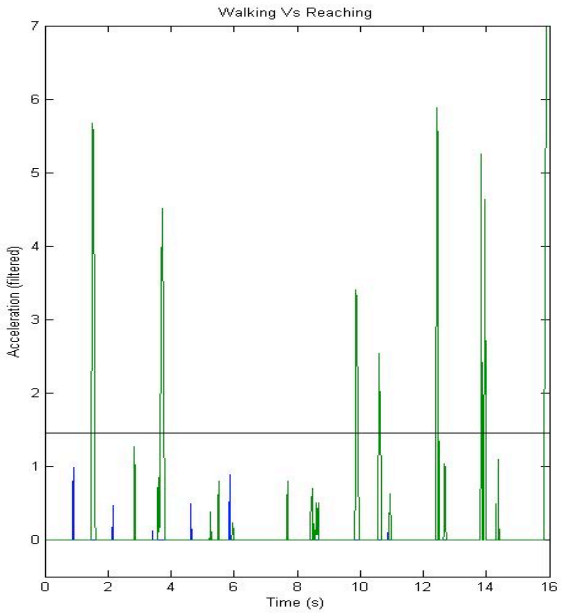

Figure 1 - A comparison of filtered activity from inertial sensors while walking with no deliberate arm movement vs. a reaching task. The blue line represents the walking task; the green represents the reaching task. Neither the filter nor threshold was optimized.

Grasp Detection

Grasp detection was accurate 25 out of 25 times tested after completing the initial setup. Setup did identify that careful configuration is necessary to avoid missed counts or double counts. This suggested that possibly an analog recording which could be filtered in a more advanced manner may be beneficial.

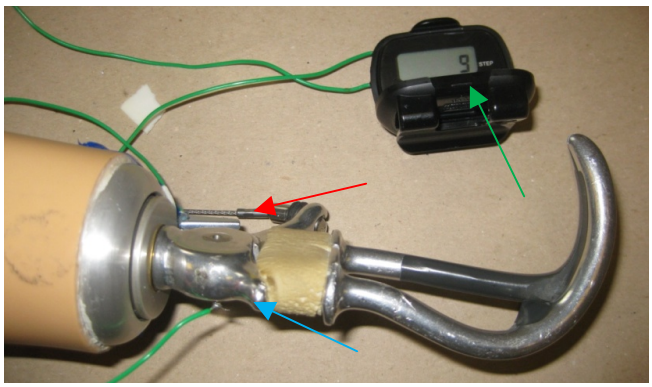

Figure 2 - A body powered prosthesis grasp monitor test using an electronic counter. Metal contacts were attached to the socket (red arrow) and hook (blue arrow); activation of the cable, which opened the hook, was captured on the electronic counter (green arrow)

Mapping Activity to Quality of Use

Movements were evaluated for suitability to be measured through instrumentation by the current device. The 22 movements of ACMC were reduced to component movements including: grasping, releasing, holding, support, positioning, timing, coordination, and visual feedback. Support refers to the user stabilizing the prosthesis in some manner. For example, by resting on a table or by holding against the body.

Table One: Instrumentation required to monitor various types of upper extremity prosthesis activities.

Movement	Instrumentation	Measureable
Wear time	Accelerometer in time blocks	Yes
Grasping	Initiation of grasp detection	Yes
Releasing	Termination of grasp detection	Yes
Holding	Initiation followed by termination of grasp detection within a time window	Yes
Stabilizing	Very low accelerometer readings	Yes
Timing	Grasp detection proximity to arm movement	Yes
Coordination	*requires an accelerometer on contralateral arm	No
Visual Feedback	*requires eye tracking	No

DISCUSSION

This abstract describes the development of a monitor of upper extremity prosthesis activity. It is designed to address the primary weakness of previous monitors by accessing both prosthetic movements as well as grasping activity. Further work is required to identify and validate thresholds for identification of movements. Future work will include validation of this monitor with motion analysis and comparison to a therapist assessment of the ACMC.

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