TAKE-HOME TRIAL OF THE GLIDE HAND AND WRIST MYOELECTRIC CONTROL ALGORITHM: A CASE STUDY

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ABSTRACT

One of the most exciting developments in the field relates to the mechatronic advances which have enabled the creation of dexterous terminal devices, wrist rotators and powered elbows. However, their clinical impact has been limited by a lack of effective myoelectric control strategies. To address this challenge, we have developed a novel control strategy based on the Postural Control algorithm, which we call the Glide Controller. In this paper, we describe the first clinical fitting of the Glide system and present qualitative results on the fitting outcomes. We also discuss the implications of this control strategy from a patient and clinician perspective.

INTRODUCTION

The disparate progression of myoelectric control algorithms and their associated multi-functional prosthetic hands has caused mismatched technologies to become available to people with upper limb amputation. Several multi-functional myoelectric prosthetic hands are available today; however users are only able to access a small subset of the total number of grip patterns which are possible [1]. The prosthetic hands typically come with several methods for accessing different grip patterns including 1) myoelectric triggers, 2) buttons on the hand, or 3) gesture control [2], [3], [4]. These switching mechanism can require up to three different steps to switch between the current grip and the desired grip. Not surprisingly, many amputees find this process cumbersome and non-intuitive [5], [6], [7]. Moreover, using muscle triggers such as a co-contraction to control multiple grip patterns or movements is considered slow, cognitively demanding and unintuitive [5], [6], [7].

An intuitive control method, called pattern recognition, is emerging, however, several hurdles remain. Many researchers (including ourselves) have turned to pattern recognition of multichannel myoelectric signals in order to develop more intuitive control of advanced prostheses including the control of grasp patterns of multi-functional hands [8]. Pattern recognition algorithms seek to correlate patterns of surface EMG activity with a given intended movement command [9], [10]. Correlation is determined by calibrating a machine learning algorithm with labelled training examples in the form muscle activity recorded while the user holds a static posture. Because these patterns are representative of natural behaviors prior to amputation, control of the prosthesis via pattern recognition is intuitive and potentially increases the number of controllable DOFs. The most significant challenge for pattern recognition algorithms is that they require highly consistent and noise-free EMG signals [6]. This is

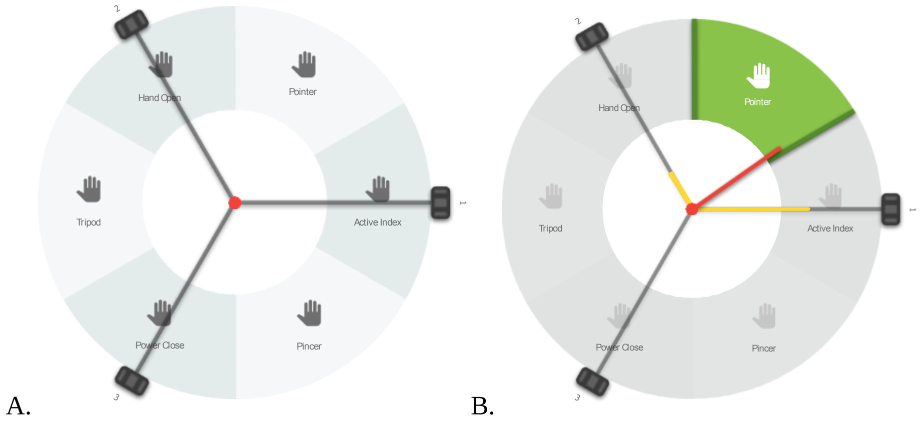

Figure 1: A. Exemplary Glide domain where the EMG electrodes (1-3) are mapped in a radially fashion. Various hand grips are placed into wedges around the domain with a null state surrounding the origin (white). B. The real-time EMG activity is present with the yellow vectors and the resultant vector (red) determines the hand or wrist function that is selected.

particularly true as the number of degrees of freedom (DOF) in prosthetic hands increase. Thus, it would be highly preferable to develop a solution that can work without any calibration or extensive subject training.

Here we present an alternative control strategy, the *Glide* myoelectric control algorithm, which maps the electromyographic (EMG) signals to a radial mapping of prosthetic hand grips or wrist functions (Figure 1). The Glide algorithm is based upon our previous work on the Postural Control algorithm in the Biomechatronics Development Laboratory [11]–[13]. The basis of Glide algorithm is the vector summation of EMG signals from 2-8 EMG electrodes which is manifested as a "Glide vector" which is projected onto the Glide domain. The domain can be partitioned into "wedges," which are correlated to single hand grips or wrist functions. A given wedge's inner radius determines the onset threshold for a movement. Once the Glide vector exceeds the onset threshold, the amplitude of the Glide vector is proportionally mapped to the velocity of the wedge's associated movement until the vector reaches the outer radius of the wedge, which corresponds to the maximum velocity of the movement. The mapping of the Glide domain is adjustable so that wedges can be placed anywhere in the domain, the inner and outer radius of the wedge can be independently changed, and the arc-length of each wedge can be made larger or smaller. These customizations allow for strong independent EMG signals to command certain functions and co-activity of other EMG signals to control other functions. The customizability ensures that the system can be fit to myoelectric prosthetic users with a broad range of abilities. Here we present a case study of a subject with trans-radial amputation who utilized the *Glide* algorithm with both hand and wrist function in a take-home trial.

METHODS

A single subject was recruited and informed consent obtained by clinicians at Handspring Clinical Service office in Salt Lake City, UT. The subject presented as a recent trans-radial amputee with a long residual limb length (8.5"). This subject was a novice myoelectric prosthetic user and had no prior experience with a myoelectric device outside of clinical sessions. The subject was originally amputated at a wrist disarticulation level but underwent a surgical revision for shortening to remove a neuroma and to improve the shape of the residual limb for prosthetic fitting. In addition, the surgeon salvaged and relocated the flexor pollicis longus muscle closer to the surface in order to provide an additional myosite for surface EMG control. The subject was fitted with a three-site *Glide* system where the electrodes were placed over the following muscles: 1) flexors digitorum, 2) extensors digitorum, and 3) flexor pollicis longus. The *Element* electrodes (Infinite Biomedical Technologies LLC, Baltimore MA) were integrated into the custom self-suspending HTV silicone prosthetic socket, the *FlexCell* battery and the *Glide* control system was integrated into the outer prosthetic socket. The TASKA prosthetic hand (TASKA Prosthetics, Christchurch, New Zealand) and wrist rotator (Motion Control, Salt Lake City, Utah) were utilized to provide the user with multiple hand grasps as well as wrist pronation and supination.

The *Glide* algorithm was configured to include the following hand grips and wrist motions: 1) hand open, 2) hand close, 3) wrist pronation, and 4) wrist supination. The gains for each of the electrodes were adjusted independently. EMG smoothing was enabled. A feature called walls was also enabled which prevents activation of a different hand/wrist function until the signal drops below the on threshold of the active Glide domain wedge.

After the subject enrolled in the study, the prosthetic system was fitted to the subject and tuned for best performance by the prosthetist. Training on use of the system was conducted by the prosthetist. The subject completed a battery of outcomes measures including 1) The McGann Feedback Form, 2) The OPUS: Satisfaction With Device and Services, 3) OPUS Upper Extremity Functional Status, and 4) OPUS: Health Quality of Life Index. The subject went home with the *Glide* system for a total of 4 weeks. Outcome measures were collected at initial fitting, two weeks post-delivery, and four weeks post-delivery. The outcome measure results and qualitative comments from the subject and prosthetist are provided here.

RESULTS

Experimental Results: The outcome measures were collected during the initial fitting, two-week session, and four-week session. Table 1 depicts the outcome measures over those sessions. The McGann Client Feedback Form results indicate an increase in prosthetic satisfaction across the four-week trial from 53% during the initial fitting to 97% satisfaction during the four-week session. The OPUS results provided a mixed description of the patient's satisfaction, functional status, and health quality in that not all outcome measures improved across the four-week session. Nonetheless, the single-subject quantitative results for the first-time use of a new technology is an encouraging step forward and suggests that the Glide algorithm can be an affective tool for the control of multi-functional prosthetic hands.

Table 1. – Outcome measure results across the initial fitting, 2-week session, and 4-week session

Experimental Session	**McGann Client Feedback Form**	**OPUS–Satisfaction with Device**	**OPUS-Functional Status**	**OPUS–Health Quality of Life**
Initial fitting	53%	39	46	74
2-week session	88%	36	30	78
4-week session	97%	38	43	73

Qualitative Results: The subject owns an excavation company and has a history of operating heavy machinery. This type of equipment utilizes joysticks with multiple switching mechanisms to manipulate the implements of the equipment. This experience was very useful for translating into prosthetic control. He was quoted as saying, "In the beginning I thought it was pretty easy. And the more and more as I go with this I recognize it is capable combining functions to do something different. So I'm getting better at it." His responses to the McGann Feedback forms indicated that as he became more familiar with the system his satisfaction increased. During the take home trial period the subject was fit with a Glide system with three electrodes. During one of the follow-up appointments he commented that he wanted to try adding a fourth electrode into the system as he stated, "I have the signals" referring to his ulnar deviators. This fourth electrode will be added in the future and further data will be collected.

DISCUSSION

Technological Progress: The Glide system is the next logical iteration of a traditional two site myoelectric control system. It has clinical implications for individuals who have had a conventional amputation surgery, but also has significant added benefits when combined with more contemporary amputation surgical methods such as TMR. From a clinical perspective it bridges the gap between a two-site myoelectric system and a full pattern recognition system. Selecting among multiple movements can be simpler than using EMG triggers such as co-contraction, double and triple impulses. While "joystick" control of the wrist is the most straightforward method to access different wedges within the Glide domain, it is also possible to use intuitive motions for control. It also bridges this gap from a cost standpoint as well. Fabrication is no more difficult or complex than a traditional two site system. The space requirements for the system are also minimal within the socket. Processing power consumption is low with no appreciable reductions in battery life as compared to a two-site system.

Clinical Perspective: There were some initial challenges in the clinical fitting as this was the first clinical application of the Glide algorithm. Part of the challenge was in learning how to refine and fine tune the arc lengths of the wedges, adjusting the gains and thresholds, enabling and disabling the walling features, and then proper queueing and instruction for the user. However, the technology proved to be quite adaptable and flexible. Initially the subject was sent home with only hand functions on the primary axis and the wrist functions as secondary fast rise actions like what a four-channel control system would be. This was challenging for him. Given his lack of myoelectric control experience he would inadvertently activate the wrist functions quite often, which proved to be frustrating to the participant. In particular when the wrist would start rotating unexpectedly and get into a unnatural anatomical posture, his whole ability to control the prosthesis would degrade. He expressed that this was because once the prosthesis was in an unnatural posture his sense of embodiment of the prosthesis completely disconnected. Fortunately, with an update to the control algorithm, wrist functionality was added as a primary function instead of as only a fast rise secondary function. Doing so allowed for defining additional Glide domain wedges for wrist control which the subject was able to activate with a high level of accuracy.

Initially when training the subject, he was queued to try and visualize moving his phantom limb as would be done in pattern recognition training and calibration. This worked to some degree, however it was never really consistent. The resultant vector would end up moving around quite a lot and not stay in one clearly defined area. It took some time to recognize that this queueing would not work and that another strategy needed to be developed. It was determined that we need to help the users conceptualize that the electrodes function somewhat like a joystick. It is best to put the primary functions right on the axis of the electrodes on the Glide domain. Once the subject has good control of each independent axis, then they can be queued to start trying to make combinations of contractions between adjacent electrodes on the Glide domain. The goal being to help the subject generate a resultant signal that is exactly in the middle of the pair of electrodes on the Glide domain. In doing so, with three electrodes six separate functions can be controlled. With four electrodes, eight separate functions could be controlled. By also allowing for fast and slow rise the potential exists to control double the amount of functions. The Glide system is not limited to the number of regions that could be created. Therefore, as an individual gains improved control in combining the signals, additional wedges can be added to the Glide domain to add additional functions. This will allow the individual to be able to access specific grip patterns of multi-articulated terminal devices as well as additional wrist functions such as flexion and extension.

Unlike in pattern recognition systems where the process of classification is somewhat obscured from the user and the prosthetists, the Glide system allows the prosthetists and the user of the technology to visually see on the Glide domain what the function will be without any ambiguity or uncertainty. It also allows the prosthetist to easily adjust the Glide domain mapping and ensure easier selection of each function. By increasing the arc of the wedge on the Glide domain and adjusting the on and maximum thresholds, the prosthetist can effectively accommodate for accuracy and fatigue of signals. Clinically, it was found to be very helpful to be able to adjust this tolerance. Past clinical experience with pattern recognition systems has shown that sometimes throughout the day as a user's muscles fatigue their classification accuracy may diminish resulting in unwanted behavior. The Glide domain interface allowed for the clinicians to adjust the wedge size and shape in order to avoid this pitfall.

Clinical Implications: A system built on the Glide algorithm provides a novel advance to traditional myoelectric control. When set up with only two electrodes it functions in the same way that a conventional two site system would. However, it provides a significant clinical advantage for controlling an increased number of functions and motions of a prosthesis when additional electrodes are added into the system. This is accomplished without time consuming additional fabrication and minimal additional hardware and processing power. Increasingly, the possible controllable motions of a prosthesis outnumber the inputs that a user has available thereby requiring complex switching strategies or signal processing algorithms in order to activate them. The limitation on a user's ability to benefit from these additional motions is correlated to the number of inputs available to them. Future applications could see connecting non-EMG inputs into the Glide system in combination with EMG signals. This could help individuals with limited surface EMG sites, such as higher level amputees, also benefit from this technology.

Because the Glide system allows for more granular control, the amount of time programming was longer than for a conventional two site system or for a pattern recognition system. There is a learning curve to the system, but over time with further fittings and documentation of outcomes a guideline of best practices will be able to be developed. This will be critical for widespread adoption by clinicians.

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