Grasp Specific and User Friendly Interface Design for Myoelectric Hand Prostheses

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***Abstract*— This paper presents the design and characterisation of a hand prosthesis and its user interface, focusing on performing the most commonly used grasps in activities of daily living (ADLs). Since the operation of a multi-articulated powered hand prosthesis is difficult to learn and master, there is a significant rate of abandonment by amputees in preference for simpler devices. In choosing so, amputees chose to live with fewer features in their prosthesis that would more reliably perform the basic operations. In this paper, we look simultaneously at a hand prosthesis design method that aims for a small number of grasps, a low complexity user interface and an alternative method to the current use of EMG as a preshape selection method through the use of a simple button; to enable amputees to get to and execute the intended hand movements intuitively, quickly and reliably. An experiment is reported at the end of the paper comparing the speed and accuracy with which able-bodied naive subjects are able to select the intended preshapes through the use of a simplified EMG method and a simple button. It is shown that the button was significantly superior in the speed of successful task completion and marginally superior in accuracy (success of first attempt).**

Fig. 1. Prosthetic hand prototype

I. INTRODUCTION

Loss of the upper limb from diseases and injuries has a devastating impact on individuals, affecting the psychological well being as well as physical functionalities and capabilities. Active (powered) hand prostheses have the potential to return some of the limb functionality as well as improve the ability for independent living and overall quality of life for people with upper limb loss.

However, a survey in [1] shows that 30-50% of upper-limb amputees do not use their prosthetic hands regularly due to the lack of capability of the prostheses, cosmesis issue and complex user interface. In recent years, the functionality and cosmesis aspect of the commercial and research hand prostheses had improved significantly [6], providing human-like multi-articulating hand prostheses, with some offering a choice of over twenty distinct grasps and pinches.

Despite these advances, the natural control of the hand for various grasps and postures is still a major shortcoming. The lack of a natural, intuitive, non-fatiguing command interface in multifunctional prosthetic hands is one the main factors that significantly affects their acceptability by the amputee community. In the short and mid terms, the user interface should allow the reliable use of the prosthesis and a short learning period to master. In the long horizon, it would be ideal to also aim for a natural user interface that allow the human user to regulate explicitly as many of the degrees of freedom in the hand as possible, thus making the prostheses more as a limb than an attached semi-automatic tool. This paper focuses on the short and mid term goals, with a consideration for the affordability of the resulting system.

Currently, state-of-the-art prosthetic hands are controlled through electromyographic (EMG) signals using surface electrodes due to their non-invasive nature, long-term stability, bio-compatibility and ethical constraints [7] in comparison to other control methods such as (implanted) brain-computer interface [10] and targeted muscle reinnervation [11]. Since extracting more than two reliable EMG signals from the residual muscle contractions required more complicated methods [2], current sophisticated commercial prostheses such as i-LIMB hand [3] and Bebionic [4] are relying on only these two signals to provide 25 and 17 grasps and postures, respectively. This results in the increase

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of control complexity, long training periods and unnatural command interface such as using mobile apps, complex timing and pulse sequences of the required EMG command signals, or using the other (able) hand for preshaping the prosthesis.

Non-commercial techniques have also been proposed in the literature that address the mismatch between the available number of independent EMG signals and the larger actuated degrees of freedom available in the hand prostheses, such as through the projection of the higher dimensional joint space of the hand prostheses onto the lower dimensional space of the EMG command [14], [15], [16], or by constructing autonomous grasping capabilities within the setting of prosthetic tasks, that is activated through the EMG signal(s) [17]. The former resulted in a relatively high complexity in the operation of the prosthesis, while the latter does not directly address how to change the intended task or preshape, focusing more on the execution of the task once determined.

The results of [8] shows that when too much effort is required to complete a grasp task, subjects do not do their best, instead, preferring less-interactive control method. They also inferred that low required attention for performing grasps is more important than grasping success in acceptability of the hand prostheses. Therefore, selecting the right trade-off between grasping capabilities and intuitive control plays an important role in satisfaction of prosthetic hand users.

In this paper, we present the design and characterisation of a multigrasp hand prosthesis with a focus on a low complexity user-friendly interface, to allow intuitive, robust and reliable control. This is done by firstly focusing on providing only the most common grasps/postures for the activities in daily living (ADL) and by secondly finding what command information is actually required to select the required pre-shape (and the easiest method to produce them). This means the user interface and the kinematics of the hand prosthesis are co-designed (simultaneously) to achieve the level of efficiency that translate into the simplicity. To this end, we first investigate the main features of a user-friendly interface. Then, the important parameters of the hand design configuration affecting the user-interface is discussed. Following the discussion, the design of a user-friendly interface is presented for performing the 6 grasps/postures that covers 75% of ADLs, with the resulting kinematic design as shown in Figure 1. This interface considers the basic information required to determine the preshapes of the grasps and postures and non-EMG-based options for the user to issue such information to the prosthesis. Presented as a discrete event system, it was determined that discrete pulse signals were sufficient, hence mechanisms such as buttons were explored to supplement the EMG signals. Finally, an experiment is carried out to assess the performance of able-bodied subjects in performing a set of grasping tasks using EMG-based and non-EMG based commands for the preshaping of the hand for specific grasp/posture.

II. Design Requirements of User-friendly Interface

As previously pointed out, one of the main reasons cited by amputees for abandoning their multi-articulating myoprotheses is the difficulty to learn and master their operation [1]. Thus the main premise of this paper revolve around the concept to achieve an easier operation of the hand prostheses, while still providing the advantages associated with multi-articulated mechanism. The following features should therefore be taken into account in the design of user-interface:

- *Intuitiveness:* The user should be able to operate the prosthesis without requiring a very high level of concentration and attention in performing a grasping or pinching task.
- *Reliability:* If the user intended to get the hand prosthesis to a specific grasp/posture (preshape), the user interface should allow, with a minimum amount of learning on the part of the human user, a high probability of successfully obtaining the correct preshape. Current commercial hand prostheses have explored the use of different EMG signal sequences and timing to do so, although results [8] showed that adapting to specific timing requires too much concentration and long training periods which results in early fatigue and unreliable control of hand movements.
- *One-hand operation:* Switching to a desired grasp / pinch preshape should be achievable without the assistance of the other (able) hand. Currently, some commercially available designs required manual repositioning of thumb for different grasps, or the option of selecting the preshape from a smart phone app.
- *Quick preshaping:* Transition from one grasp to another grasp should not take too much time.

In order to realise the characteristics of the user-friendly interface above, several important parameters should be considered: the most commonly used grasps, number of desired grasps/postures, number of the actuators (and kinematic design of the hand) required for realisation of the desired grasps/postures and the required information feedback to the user for an effective operation of the prosthesis.

A. Grasp and Posture Selections and Realisation

As mentioned in the Introduction, there is trade-off between number of grasps/postures that can be provided by the existing two-input EMG system and the operation complexity of the user interface. Therefore, a well considered selection of desired grasps/posture has a significant effect in design of user-friendly interface. A study of the dexterity required for the hands [5] showed that 95% of the daily activities can be achieved using the following grasps/postures: a spherical grip (required for 10% of the tasks in daily living), a tripod (10%), a cylindrical power grip (25%), a lateral grip (20%), a tip grip (20%), and an extension grip (10%).

In this paper, we would like to realise the four most commonly used grasps: cylindrical grip, tip grip, key grip and

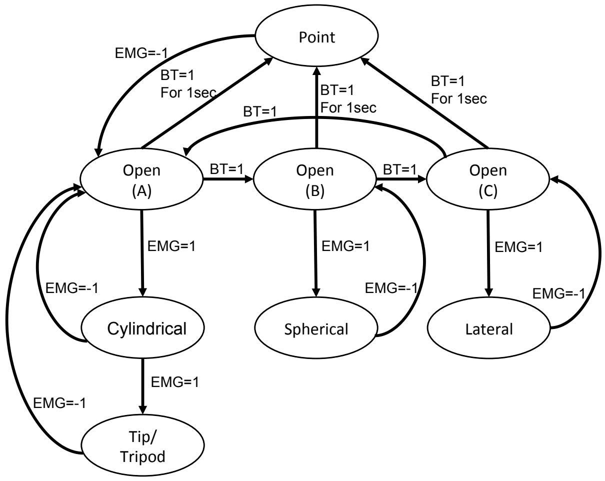

Fig. 2. Schematic of the strategy to operate the resulting hand prosthesis presented as a finite state diagram. EMG = 1 and -1 refer to actuation command from the two EMG signals, respectively and BT = 1 refers to a trigger signal

spherical grip. Combined, these grasps will cover 75% of the daily activities as reported in [5]. In addition to these grasps, a pointing posture is also included for it communication context in a conversation and due to its use in basic keyboard typing and in the recent prevalent use of communication devices that leverages the touch screen interface such as the smart phones.

The grasps and pinches are realised through two mechanisms: a) kinematic design of the thumb, allowing 3 distinct thumb locations (A-spherical; B-lateral; C-cylindrical); b) differentiating the formation of grasps and pinches through the difference in the relative displacement of the thumb with respect to the other fingers.

Considering the above mechanisms, the grasps/postures are realised as follows (refer to Figure 2):

- *Open posture:* All the fingers are in open position and thumb by default is in cylindrical position. The successive triggering of the thumb actuator moves the thumb from cylindrical position (A) to lateral position (C), from lateral to spherical position (B) and then returns to the cylindrical position.
- *Spherical power grasp:* While the thumb is in spherical position, little and ring fingers will contract further than the index and middle fingers and the thumb contracts less than all the other fingers, for a unit change in EMG signal. Extended actuation of the hand using EMG signals in this preshape of the thumb allows the hand to eventually form a fist thus can be used for grasping small cylindrical objects like pen and marker.
- *Cylindrical power grasp and tip pinch:* While the thumb is in cylindrical position, the four fingers will move with the same displacement (per unit change in EMG command) and the thumb will move such that they meet in the centre to form the tip pinch. If the fingers are stopped before reaching to the tip pinch by grasping a big cylindrical objects, it will form cylindrical grasp.
- *Lateral grasp:* In lateral position of thumb, if the thumb moves with relatively less displacement per unit of change in the EMG command, it would allow the other four fingers to close completely, then it forms the lateral grasp.
- *Point posture:* In any position of thumb, if the button is hold for more than one sec, then it forms pointing position where thumb will move to the lateral position, little, ring and middle fingers will close completely and index finger will be in open position.

In the following subsection, other important parameters in design of a user-friendly interface are discussed.

B. Other effective parameters in design of interface

The number of available actuators for the realisation of the desired grasps/postures is another important parameter that follows from determining the required grasps and postures. Currently, commercial hand prostheses have from 1 to 6 actuators and research grade prosthetic hands have anything from 1 to 16 actuators [6]. Although increasing number of actuators provides more dexterous hand, the control of the hand requires many control input signals to realise this dexterity. For the moment, this introduces a high level of complexity and a long learning duration. Therefore, selecting the right number of grasps and posture, hence number of actuators, is crucial in the design of user-friendly interface, at least as the current immediate solution.

The kinematic of the hand design is not the main focus of this paper, thus will only be addressed briefly along to highlight its role in this paper. The analysis of the required grasps in Section II-A showed that it was necessary to independently actuate (1) the index and middle finger, (2) the ring and little fingers, (3) the contraction of the thumb and (4) the three distinct thumb locations. Through the use of underactuated fingers, each finger requires only one motor, though the stiffness of the joints in each finger need to be designed to determine the relative displacements of the phalanges for a unit change in actuation. In this paper, however, it was decided to actuate the index and the middle fingers independently, such that the synchronisation of the motion of the two fingers are done through closed loop control, instead of through mechanical means. As such, the designed hand utilise 5 motors in its design to achieve the required grasps and postures. Further details on the hardware realisation is given in Section III.

The user interface feedback to the human user in another factor in the interface design. The feedback can be used in high-level control to human such as vibrotactile or audio feedback for control of the force closure or in low-level control to the hand controller such as stopping the grasp at specific level of force exerted to the object. In the cases that the user regulates the level of contact grasping force, a continuous signal should be provided by interface to the user. Furthermore, it is necessary for the user to know which state the hand prosthesis is in at any point in time, e.g. where it is in open idle state or in which grasp preshape it is in.

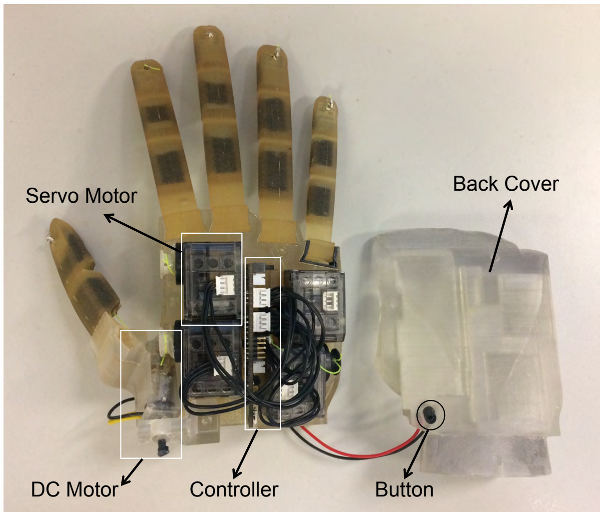

Fig. 3. Actuation configuration of the prosthetic hand prototype

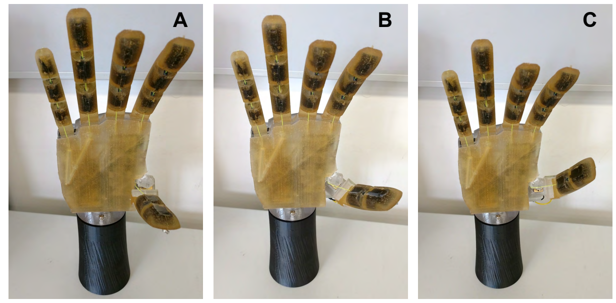

Fig. 4. Three thumb position: A) Cylindrical; B) Spherical; C) Lateral.

The transition sequence between grasps is another important parameter. The user should be able to reach the intended preshape with the minimum length of command signal. In this paper, we consider the cylindrical preshape as the default preshape since it is the most commonly used. In this preshape the user can perform the cylindrical power grasp and tip pinch (45% of ADLs). By sending the command control, the preshape switches to the lateral preshape (20% of ADLs) and then switches to spherical preshape (10% of ADLs). With this sequence, all the preshapes are available with sending command signal once or twice. I addition, triggering the thumb actuation system for more than one second, in any preshape of the hand, will result in pointing posture. This transition strategy is shown in Fig. 2.

It should be noted that the current preshape for different grasps should be distinguishable to the user (e.g. visually). For example, the preshape of the tip and tripod grips are the same so the user needs an indicator to know which grasp has been selected and will be performed from this preshape. In this paper, since the preshapes of the hand are distinguishable visually, no extra feedback is required.

The method of sending command signal affects the reliability of the user interface. Currently, most of the commercial hand prostheses are using EMG-based command signals to control the hand [19]. Due to the intrinsic time-varying characters of the EMG signals resulted from temperature, moisture, sweating on sEMGs, as well as the inherently lower signal to noise ratio of the electrode worn on the skin, they have limited reliability for control of the hand. In general, a fair amount of low pass filtering is required for the raw signal. Therefore, there is a significant argument obtaining accurate and repeatable signals in terms of signal duration, magnitude, or even in identifying a rising or falling edge required in the hand prostheses. Some of the prosthetic hands have non-EMG based means of issuing commands such as an array of buttons in back of the hand [4] or mobile apps [3] although these methods require the other hand for execution.

In this paper, we proposed using a button at the back of the prosthetic hand, which protrudes above the surface of the hand thus allowing it to be mechanically activated by pressing the back of the hand against another surface, such as one's own thigh, or the side of a bench; thus allowing one-handed operation. Specifically, this button is located below the thumb towards the back of the hand. Its trigger is used to scroll through different grasps and pinches as shown in Fig. 4.

III. Hand prototype design and realisation

The overall objective of the experimental hand prototype design is to realise the desired grasps/postures and user-friendly interface explained in the previous section, while providing the advantages of being human-like in appearance, light weight, one handed operation and intrinsic actuation system.

In contrast to robotic hands, in prosthetic setting, the user is not able to control large number of DOFs, therefore, the underactuated prosthetic hands which are using fewer actuators than degrees of freedom (DOF) are more desirable and also they have shown good performance at moderate cost and size of the hand [12]. In [9], it has been shown that compliance allows an adaptive grasp of objects with different shapes and provides successful and stable grasping for a wide range of target objects. In addition, compliant joints provides more "human-like" movement of fingers.

Considering the underactuation and compliance features of the hand, minimum number of actuators required to realise the desired grasps/postures is determined. The actuation system consists of five motors embedded in the hand: 4 smart servo motors (Dynamixel XL-320) and 1 DC motor (Pololu micro motor). Three of servo motors are actuating index finger, middle finger and thumb and the ring and little fingers are co-actuated with one servo motor. A DC motor is used to change the position of thumb located in such a way that with actuation of DC motor we can implement 3 different opposition configuration for the desired grasping tasks. A potentiometer is used to identify the location of the thumb. The transmission mechanism from motors to fingers is tendon. Actuation configuration is intrinsic and all the actuators, motor drivers and the controller are embedded in the hand structure as shown in Fig 4.

Fabrication of hand consists of two main techniques: 3D

TABLE I

COMPARING PROTOTYPE HAND WITH THE COMMERCIAL PROSTHETIC HANDS

	Weight	No. of actuators	DOF
Prototype hand	350-375gr	5	6
SensorHand (OttoBock)	350-500 gr	1	1
Michelangelo	420gr	2	2
BeBionic v2	495-539gr	5	6
iLimb Pulse	460-465gr	5	6

printing and SDM (Shape Deposition Manufacturing) [18]. Palm, back cover and skeleton of fingers are 3D printed. The SDM technique is used to fabricate the fingers and palm cover. Each of four fingers (index, middle, ring and little) consists of 3 phalanges, connected by compliant joints. The tendon is attached to the fingertip and goes through the 3D printed finger skeleton and connected to the motor spools.

The weight of the hand prototype including the embedded actuators and controller is 350gr. Based on the anthropometric norms [13], an average male hand size (breadth 9cm and length 19cm) is adopted in the design of hand. The specification of the prototype hand and available prosthetic hand in the market are listed in Table I.

The hand is controlled by using only two sEMG (surface electromyography) signals provided by most of commercial EMG electrodes for opening and closing the hand and one simple tactile button located below the thumb towards the back of the hand to scroll through different hand preshapes.

IV. EXPERIMENTS

The objective of the experiments is to compare the performance of naive able-bodied users in obtaining the intended preshape in the prosthetic hand using (1) EMG commands and (2) a single button. The use of naive able-bodied subjects is comparable to a realistic scenario of an amputee who is new to the operation of a myoelectric hand prosthesis (who will be learning to use the hand prosthesis).

A. Methods

The experiment is conducted with 10 able-bodied subjects (2 females and 8 males). Prior to the start of the experiment, the finite state diagram of the thumb position scrolling is explained to all participants followed by a demonstration on the prototype hand. We explained and demonstrated to subjects that in the lateral position of the thumb if they trigger the thumb actuator (using the button shown in Fig. 4 or making fist gesture to produce an EMG signal), it will move to the spherical position. If they trigger it again, it will move to the cylindrical position and with the next trigger it will return to the lateral position. Therefore, specific number of triggers is required to move from one position to another position (Lateral to Spherical: 1 trigger; Lateral to Cylindrical: 2; Spherical to Cylindrical: 1; Spherical to Lateral: 2; Cylindrical to Lateral: 1; Cylindrical to Spherical: 2). The subjects can see the position of the thumb in the prototype hand in front of them. They should memorize this sequence and in the cases that they cannot recall it, they had to figure it out by trial and error which is penalised in the success rate and task time.

In the phase one of the experiments, the participants were asked to scroll to 10 different position of the thumb (Spherical, Cylindrical, Spherical, Lateral, Cylindrical, Lateral, Spherical, Lateral, Cylindrical, Lateral). Each desired position of the thumb was displayed on a laptop screen. Then, they had to move the thumb to the desired position by pressing the button shown in Fig. 4 and press the space bar of the laptop as a finish button to announce that they think the task is complete and thumb is in the desired position. Then, a program in the MATLAB will check the position of the thumb and if it was in the desired position, it will display this message: ”Successful task operation” and the next desired position is displayed. If it was not in the desired position, it will display this message: ”Unsuccessful task operation” and the desired position is displayed again. If they move the thumb to the desired position but with more triggers than explained above, it will display this message: ”Successful task operation but with more number of toggles” and the next desired position is displayed. They will repeat this set of 10 tasks for 3 times (overall 30 tasks).

In the phase two of the experiments, the same procedure explained above is repeated by using EMG commanding method instead of the button. An EMG signals is provided using Myo™ band for the ease of use and it is used like a standard two EMG electrodes. Making fist gesture by subjects produces a signal which is sent to the controller.

The success of the preshaping is the first parameter to be measured. The task is called successful if specific number of the triggers required to reach the desired position of thumb is executed. For example, to change the preshape of the hand from lateral to spherical only requires one press of button or one trigger of EMG signal; if the participant registered more than one trigger then it will be considered as unsuccessful. In addition, if they press the finish button while the thumb is not is the desired position, it will be considered as unsuccessful task operation as well.

The second parameter is the time for successful task completion, which is defined as the time that desired position is displayed to the participant on the screen until the time that thumb is in the desired position and participant presses the finish button. If they press the finish button while it is not in the desired position, they should repeat the experiments until it is in the desired position which will increase the task operation time.

B. Results and Discussion

The results for the success percentage and task operation time using button and EMG for the subjects are presented in Fig. 5 and Fig. 6, respectively. The results for the successful attempts in Fig. 5 show higher percentage of successful task operation using button as a trigger mechanism than the EMG in all the subjects. The experimental results (Fig. 6) demonstrated that the time required to perform the tasks

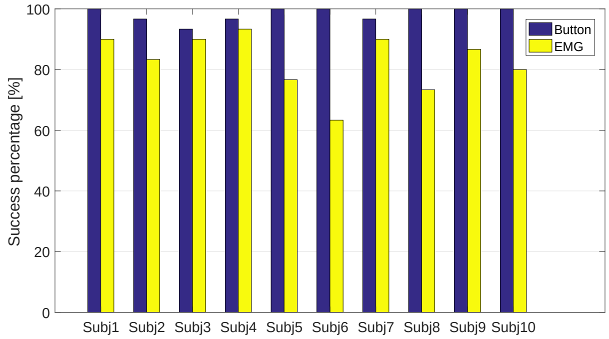

Fig. 5. Success with minimum number of triggers

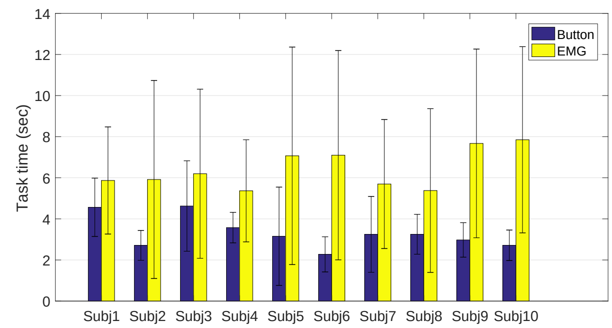

Fig. 6. Task operation time

TABLE II

OVERALL RESULTS OF THE PRESHAPING PERFORMANCE USING EMG AND A BUTTON

	Button	EMG
Average task time	3.33 sec	6.44 sec
Average success percentage	98.33%	82.66%

using EMG is approximately twice the time of using button for each subject. The overall results of all the subjects in summarised in Table II.

Also subjective opinion of the subjects in comparing these two methods showed that in using EMG, higher level of attention is required to perform the tasks and also they experienced high level of fatigue.

V. CONCLUSIONS

A concept is summarised and presented in this paper towards realising a hand (motorised) prosthesis that is designed to perform a small number of grasps and postures well. Selection of the grasps and postures to be realised would be purpose specific, and in this paper, we simply took the justification as presented in [5]. These grasps and posture were used to determined the simplest kinematics capable of realising them and are then organised in a finite state diagram so that they could be selected by scrolling through a series of preshapes using a trigger mechanism and executed using the continuous EMG signals. To further the simplification, we proposed the use of a simple button for the said trigger mechanism rather than using the EMG signals as per current practice in the industry. A quick experiment demonstrated that the first time subjects were more effective performing the task of selecting the right preshape using the buttons than through the attempt of producing the right EMG signals. This has the potential to significantly reduce the difficulty in learning to operate a myoelectric hand prosthesis.

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