VOICE RECOGNITION CONTROL OF A MULTI-ARTICULATING HAND FOR IMPROVED GRASP SELECTION

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ABSTRACT

About half of upper-limb (UL) amputees do not wear a prosthesis. This is, in part, related to an inability to take full functional advantage of the prosthesis. To help address this issue, we have developed the Voice Activated Prosthesis Interface (VAPI) to allow individuals to supplement their conventional control with voice commands. Specifically, this study targeted accessing multiple grip patterns in multi-articulating hands. Data from amputee test subjects is reported showing an improvement in the time to complete tasks, more accurate grip selection, and reduced frustration with the prosthesis when using the voice recognition technology compared to standard myoelectric control.

INTRODUCTION

It is generally agreed that only about half of upper-limb (UL) amputees wear a prosthesis [1,2]. This is often because the prosthesis does not return enough function for the burdens of weight, discomfort, non-cosmetic appearance, lack of durability, etc. [3]. One primary reason for the lack of prosthesis acceptance is the inability to control the device effectively. Difficulties with control result because multiple prosthetic joints are being controlled with a limited number of inputs from the user. The issue becomes even greater with more proximal amputation as there are even more joints to control with even fewer inputs available.

Current input options for UL amputees are limited and include switches, electromyographic (EMG) inputs from residual musculature, force sensitive resistors, linear transducers, etc. In addition, many amputees don't have the ability to use these inputs effectively (e.g., muscle atrophy can lead to unusable EMG signals). Also, conditions such as traumatic brain injury or other cognitive deficits can make it difficult to understand and produce reliable input signals. Even for proficient users, most current control strategies often require sequential control of the various system joints.

The lack of independent and intuitive control inputs also leads to existing complex prosthetic mechanisms being underutilized. For example, in recent years there have been substantial advancements in prosthetic mechanisms such as multi-articulating hands (Figure 1). These hands have the ability to produce dozens of different grip patterns that can be selected based upon the task being performed. However, grasp pattern selection can be complex and difficult to understand. Therefore, most users only utilize a maximum of four hand grasps due to the difficulty in reliably switching between grip patterns.

VOICE ACTIVATED PROSTHESIS INTERFACE

Upper limb amputees are looking for solutions that allow them to regain the function they lost after their amputation. To address this need, Liberating Technologies, Inc. (LTI) has developed the Voice Activated Prosthesis Interface (VAPI) controller which incorporates the ability for the amputee to use their voice to generate control signals for their prosthesis.

Speech is the most natural and highest bandwidth mode of communication for humans [4]. Therefore, we aim to augment users current control schemes with the addition of their voice as a new input modality. Using this approach, VAPI has the ability to access larger numbers of grip patterns within multi-articulating hands as well as fluidly perform tasks that require coordinated sequential movements of multiple prosthetic joints, such as opening a door.

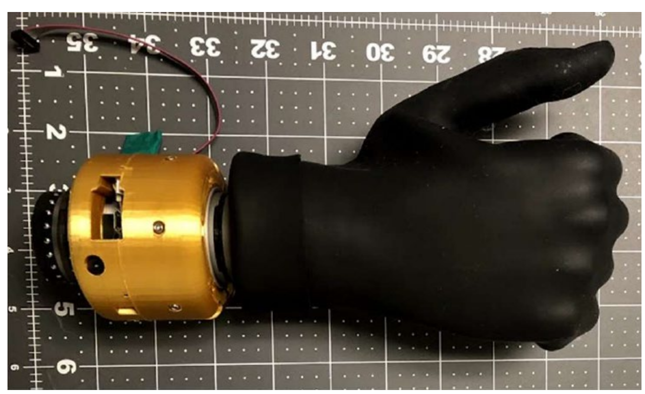

Figure 1: *Prototype VAPI with iLimb Hand*

LTI has prototyped a fully embedded and stand-alone VAPI controller (Figure 1) to demonstrate feasibility of the concept. The current phase of research has been focused on developing three major components of the VAPI system: (1) the 'command interpreter' which interprets the commands through the voice recognition engine; (2) the 'command

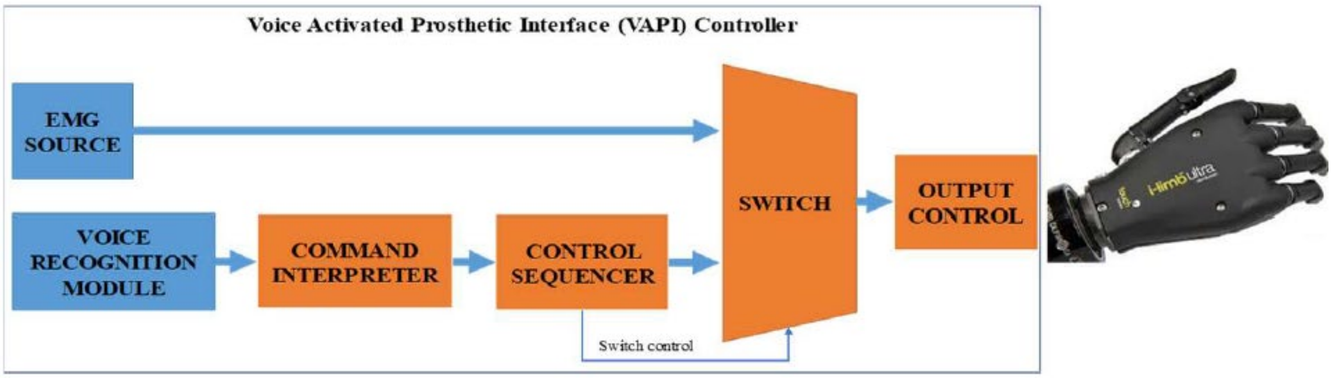

Figure 2: *Voice Activated Prosthesis Interface (VAPI) quick disconnect controller architecture.*

sequencer' which determines what control signals to generate based on the voice command; and (3) at the output controller to drive the terminal device (Figure 2).

As demonstrated in Figure 2 the VAPI is used in addition to the user's standard EMG signals, with the control sequencer determining if the EMG or voice inputs will control the terminal device. The VAPI system uses a trigger word to 'wake up' the voice recognition module (e.g., 'Alexa…') which then listens for the command word. This helps to reduce accidental activation of the prosthesis. After receiving the voice command, the VAPI produces the necessary command signal to elicit a grip change in the hand. Control is then relinquished back to the EMG sensors for the user to open or close the hand after the correct grasp pattern has been achieved.

VOICE COMMANDS AND RECOGNITION ACCURACY

With our partners at eSoftThings and Sensory, Inc., we developed a series of phonetically distinct command sets to test to determine which would produce the highest classification accuracy. Preliminary tests had six subjects perform five trials of each word in eleven different command sets. Figure 3 demonstrates that we were able to elicit up to 98% recognition accuracy for two of the command sets (#2&#8). The command set that was selected for future testing included the command words: "finger pinch," "power grip," "tripod," "key grip," "hand," and "wrist," with the latter two being used to toggle between hand and wrist control.

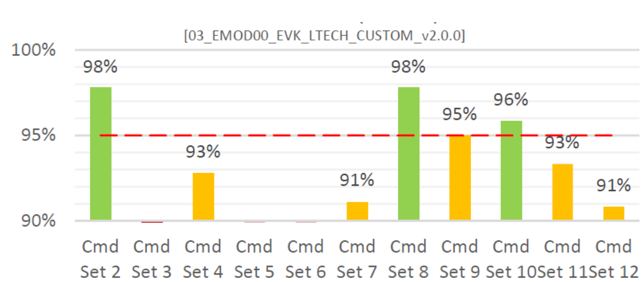

Figure 3: *Recognition accuracy results over 30 trials for each command set. Our goal was 95% (red dotted line).*

FUNCTIONAL OUTCOMES TESTING

Methods

We performed a set of standardized functional outcomes measures including the University of New Brunswick (UNB) Test of Prosthesis Function. While this test was originally intended for children, there has been shown to have acceptable reliability and preliminary evidence of validity for adults [5]. In addition to the UNB, we worked with our study Occupation Therapist (OT), Dr. Debra Latour, to develop a set of custom tasks that represent activities of daily living (ADL) where multiple grasp patterns may be useful. These included pouring and drinking, dressing tasks (put on sock, tie shoelaces, zip vest), turn doorknob, wrap a package and add written address label, etc.

Ultimately the user needs to generate the appropriate control signals to make the desired grip change. However, users will not always be able to switch into the desired grip pattern at the desired time. This could be due to imprecise muscle coordination (e.g., producing a double impulse when a triple impulse is required, not holding 'hold open' long enough, etc.), fatigue, misinterpreted voice commands, etc. Therefore, in addition to scoring the tests described above, we also tracked how often the subjects were not able to switch into the desired grip (i.e., 'Missed Grips').

Each subject completes the battery of tests either using EMG-only control or EMG with Voice Recognition (VR) control. Each subject was provided with an iLimb Ultra hand and VAPI for testing. In EMG-only mode, the hand was programmed to have four different mode switching commands used to access four different grip patterns within the iLimb (i.e., lateral, 3 jaw chuck closed, cylindrical, and precision pinch closed) via standard EMG switching commands including hold open, double pulse, triple pulse, and co-contraction. To ensure the length and weight of the prostheses were the same in both test conditions, the VAPI was installed, but disabled, during EMG-only control.

The subjects were trained on the VAPI and EMG switching and allowed to practice with each until they indicated they were comfortable with the control. Each subject then completed three trials of each task including both the UNB and custom tasks to simulate activities of daily living (ADLs).

Results

We have tested two subjects with limb loss thus far and testing is currently ongoing. We will have more subjects (both amputee and able-bodied) completed by the conclusion of the research funding in June of 2020. One subject with limb loss was an experienced two-site EMG user with a Touch Bionics iLimb multi-articulating hand. The other was a novice two-site EMG user with a Steeper beBionic multi-articulating hand. The experienced user was able to complete the full set of tasks three times. Due to fatigue, the novice user was unable to complete the full set of tasks. The novice user fatigued, in part, because the hand used for testing was significantly larger than their usual hand and the subject was unaccustomed to the additional weight.

UNB: Traditionally the UNB focuses on scoring spontaneity and skill. The measure of spontaneity defines a person's tendency and impulse to use their prosthesis effectively when attempting a two-handed task. In determining a person's level of skill, it may be evident that the person is able to perform the requested task but demonstrates the need for additional training or motivation to refine their abilities when using their prosthesis [6]. Scoring results from the UNB did not show a substantial improvement in spontaneity or skill for VR.

Timing: One of our original hypotheses was that voice recognition control would allow the user to complete their tasks faster. Our experienced user demonstrated that they were able to complete the tasks ***35% faster*** (13.3 seconds to 8.6 seconds) when using voice recognition (Figure 4).

Missed Grips: The experienced two-site myoelectric user that completed the full three rounds of testing was observed to have made 2.8 times more grip switching mistakes when using EMG-only control than when they used voice control (Table 1). These results were consistent across both the UNB and custom tasks. In addition, with EMG-only control, each missed grip would require an additional muscle exertion to achieve the desired grip.

Anecdotal Feedback: Missed grip changes were a substantial source of frustration for both control methods. Survey results demonstrated that both subjects preferred the voice control and had lower frustration levels with VR due to fewer grip transition mistakes. One user reported reduced exertion when using the voice control. Both subjects also reported frustration with the length and weight of the prototype system.

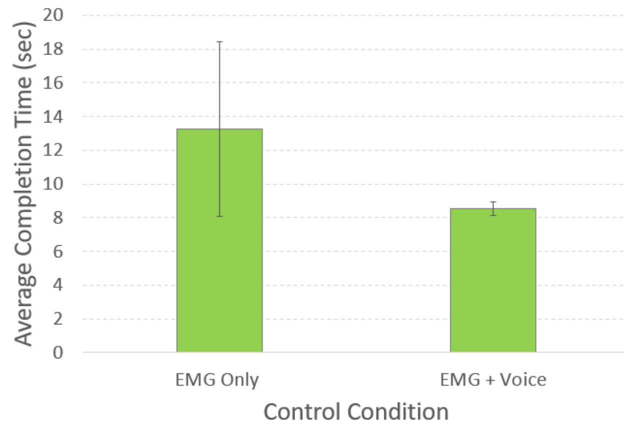

Figure 4: *Average task completion time with 95% confidence intervals with EMG Only grasp selection or EMG with voice control grasp switching.*

Table 1: Number of Missed Grips per control condition.

	Control Method		**Ratio (EMG only/ EMG+Voice)**
	EMG-only Control	***EMG + Voice Control***	
Missed Grips	51	18	2.8

DISCUSSION / CONCLUSION

Preliminary data indicates that voice recognition control of an upper limb prosthesis demonstrated more accurate multi-articulating hand grip selection than standard EMG-control methods. These data also indicated that it is possible to complete tasks more rapidly with voice control.

We believe that as individuals are able to easily and reliably access a greater number of grip patterns, they will be more likely to select the grip pattern that is ideal for the task at hand. With proper grip selection, it is likely that individuals will be able to reduce compensatory movements, which have been shown to lead to long term overuse injuries and joint damage [7].

It should be noted that there are other methods that can be used for selecting grip patterns that were not investigated in this study. These include the use of pattern recognition systems as well as the gesture control built into the iLimb Quantum. While these alternative methods are promising, there is a ceiling to the number of grasps that can be accessed through these methods. It has been reported anecdotally that pattern recognition can reliably access three to four grip patterns and the gesture control adds four patterns. We plan to compare voice recognition control to these methods in future trials.

FUTURE WORK

Testing of the VAPI system is currently ongoing with three additional amputee subjects and several able-bodied subjects to be completed by June 2020.

In addition to testing the current system, we are continuing to make further technical enhancements to the VAPI system with our current funding. One enhancement is to implement remote microphones, such as lapel or in-ear microphones, to detect and wirelessly transmit the voice commands to the VAPI for processing. This will move the microphone from its current location in the wrist, which has the potential to be interfered with if the individual were to choose to wear clothing such as a heavy, long-sleeved jacket. We will also investigate communicating directly with a multi-articulating hand itself over Bluetooth to be able to access an even larger number of grip patterns.

Finally, we are in the process of developing a new outcome measure specifically designed to assess the ability of individuals to access different grip patterns. We refer to this test at the Grip Switch Assessment (GSA). The GSA was inspired by the Box and Block Test, a commonly used measure to assess unilateral gross manual dexterity. The GSA was designed to measure a user's ability to efficiently switch between multi-articulating hand grips while manipulating simple objects. The assessment involves measuring the time it takes for a user to switch into the proper grip and carry a set of objects over a short obstacle (Figure 5). If the patient takes longer than 30 seconds to achieve the proper grip the test administrator will have the patient move onto the next item. This cut-off reduces the continued frustration of the patient and keeps the GSA trial time to under two minutes. The order of the objects is randomized with each trial.

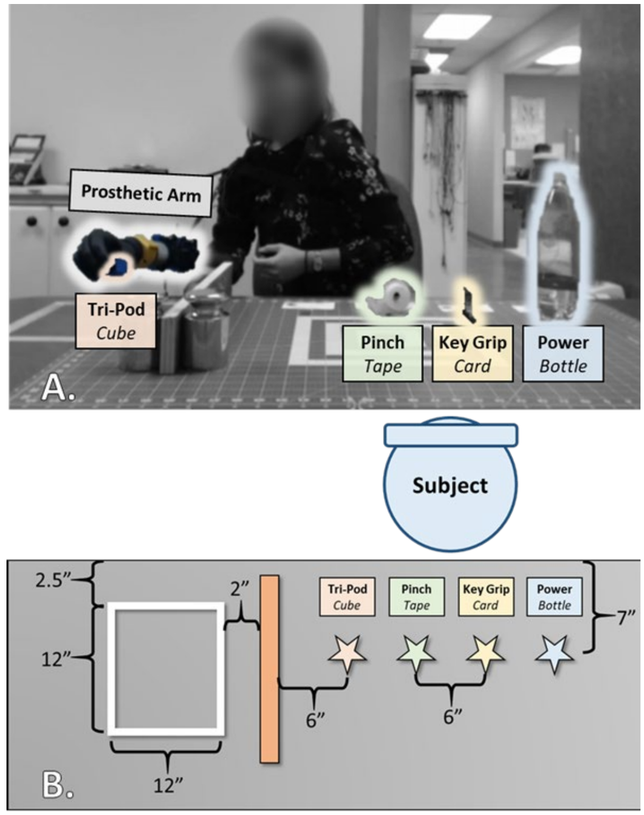

Figure 5: *A - An able-bodied participant manipulating the first object during a GSA trial. B - A diagram of the table arrangement to administer the GSA for a patient affected in the right arm.*

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