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Applying Space Technology to Enhance Control of an Artificial Arm for Children and Adults with Amputations

Introduction

The first single function myoelectric prosthetic hand was introduced in the 1960's. This hand was controlled by the electric fields generated by muscle contractions in the residual limb of the amputee user. Electrodes and amplifiers, embedded in the prosthetic socket, measured these electric fields across the skin, which increase in amplitude as the individual contracts their muscle. When the myoelectric signal reached a certain threshold amplitude, the control unit activated a motor which opened or closed a hand-like prosthetic terminal device with a pincher grip. Late in the 1990's, little has changed. Most current myoelectric prostheses still operate in this same, single-function way.

To better understand the limitations of the current single-function myoelectric hand and the needs of those who use them, The Institute for Rehabilitation and Research (TIRR), sponsored by the National Institutes of Health (NIH), surveyed approximately 2,500 individuals with upper limb loss [1]. When asked to identify specific features of their current myoelectric prostheses that needed improvement, the survey respondents overwhelmingly identified the lack of wrist and finger movement, as well as poor control capability. However, simply building a mechanism with individual finger and wrist motion is not enough. In the 1960's and 1970's, engineers built a number of more dexterous prosthetic hands. Unfortunately, these were rejected during clinical trials due to a difficult and distracting control interface.

The goal of this project, "Applying Space Technology to Enhance Control of an Artificial Arm for Children and Adults with Amputations," was to lay the foundation for a multi-function, intuitive myoelectric control system which requires no conscious thought to move the hand. We built an extensive myoelectric signal database for six motions from ten amputee volunteers. We also tested a control system based on new artificial intelligence techniques on the data from two of these subjects. This data is available to anyone doing myoelectric control research. Its availability is an important contribution to the prosthetics research community, as many researchers do not have access to amputee subjects. Since we collected myoelectric data from subjects' sound arms as well as their residual arms, this database will also prove useful to virtual reality and robotics researchers who want to explore myoelectric-based interfaces between any user and a machine.

Currently, one small company (Intelligenta, Inc.) and one university (University of New Brunswick, Canada) are using this myoelectric database under other funding to develop multifunction control systems for prostheses. A prosthetics manufacturer (Liberty Technology, Inc.) is making plans to incorporate the results of their work into an artificial hand capable of several different movements to provide functionality only dreamed of by current myoelectric users.

Methods

Six adults and four children, all with unilateral, below-elbow amputations served as subjects. Five of the adults (3 male, 2 female, average age 34 years) had amputations due to traumatic injury, while one adult (female, age 32 years) and the four children (3 male, 1 female, average age 13 years) had congenital (i.e. from birth) limb deficiencies.

For nine subjects, we placed four pairs of surface electrodes on the sound forearm and four pairs were placed on the residual forearm, in locations that provided the best myoelectric data. In the tenth case, we used five pairs on the amputated side to explore the potential of increasing the number of channels in improving discrimination of the different motions. We recorded myoelectric signals at 2000 samples per second as the subjects performed one of six motions: open grasp, close grasp, flex wrist, extend wrist, pronate forearm, and supinate forearm. A picture of one of these six motions appeared one at a time in a random order on a computer screen and the subjects imitated the motion, simultaneously moving both their sound hand and their phantom (traumatic case) or imaginary (congenital case) hand. Each of the six motions was randomly presented to the subjects up to approximately 150 times. We recorded about 700 trials for each of the first two subjects, but more than 900 trial motions per person for the last eight subjects. Rest breaks and meals were given as needed. Due to the high speed data collection system developed for this project, total testing time for each subject was only about three hours, a major improvement over previous data collection efforts. Myoelectric data was collected through a myoelectric amplifier and signal conditioner, then stored on computer for later analysis.

In addition to the myoelectric data, we used Magnetic Resonance Imaging (MRI) to map the musculature of both the residual limb and sound limb of the five subjects with congenital limb deficiency. The degree to which the anatomy of the residual limb of an individual with congenital limb deficiency resembles that of a traumatic amputee's residual limb has been a mystery. Also, how closely the development of the congenitally deficient limb follows that of the individual's sound limb is unknown. Different causes of congenital amputations, many of which are unknown, may produce different residual limb anatomy in different subjects. Many experts believe that the most common cause of these congenital amputations should result in a residual limb that is similar to the residual limb of a traumatic amputee.

Data Analysis and Results

Control System Development. We have tested a control algorithm based on genetic programming (GP) on two subjects' data. GP mimics the natural biological process of evolution; however, it works on computer programs instead of living species. It is especially well-suited for solving problems where the form of the eventual solution is completely unknown, whereas the next-best technique, artificial neural networks, restricts the solution structure considerably, allowing only weights within a given structure to adapt. Our preliminary results using data from two individuals with traumatic upper limb loss shows that our genetic programming-based approach is superior to any approach tried to date, averaging 95% successful discrimination for these six wrist and hand motions over hundreds of trials. We have published one paper on myoelectric control results of this approach [2]. Dr. Kristin Farry, our NASA/JSC collaborator, is working on two more for an international myoelectric prosthetics conference in 1999 (Myoelectric Control '99) and journals IEEE Transactions on Biomedical Engineering or Rehabilitation Engineering.

Table 1: Results for two subjects with traumatic amputations are very promising.

Subject Identifier	Number of Electrode Sites	Motion Discrimination Accuracy						Average for All Motions
		Open Grasp	Close Grasp	Extend Wrist	Flex Wrist	Supinate Forearm	Pronate Forearm	
1	4	95.7%	97.6%	94.2%	95.1%	96.1%	91.7%	95.1%
2	5	91.4%	99.5%	93.5%	94.4%	94.8%	93.7%	94.9%

Imaging. Analysis of the MRI films shows that all five subjects with congenital limb deficiencies have abnormalities in the radioulnar joint, which is proximal to (above) the end of their residual limbs. By contrast, traumatic amputees with no damage to the elbow have normal radioulnar joints. Thus, we can no longer assume that congenital and traumatic below elbow limb loss anatomy is similar.

All subjects had a full complement of forearm musculature in their residual limbs, albeit undeveloped. TMC radiologists identified and measured each muscle in the subjects' forearms. Radiologist Dr. Larry Kramer, our University of Texas collaborator, is co-authoring a paper summarizing these statistics for a medical journal. Dr. Farry will present them at the Myoelectric Control '99 conference.

Phantom Limb. All subjects with traumatic limb loss reported having a sense of still having the hand they lost, a "phantom hand" that they could visualize moving. Most reported some minor limits (usually inability to completely open or close the fingers) on the phantom limb motion that they could sense. Performing the desired motions was generally quite easy and intuitive for the traumatic group.

Prior to our data collection sessions, all subjects with congenital limb loss reported NO perception of a ghost or "phantom" hand like that reported by traumatic amputees. We asked these subjects to develop a prosthesis command set that they could easily remember and associate with the proposed prosthesis movements. All chose to imagine moving a hand through the prosthesis motions. Within a few hundred motion trials in which they visualized moving this imaginary hand along with their sound hand, subjects reported developing a perception of the missing hand well beyond pure imagination. A preliminary look at the myoelectric activity recorded from their residual limbs while they moved this imaginary hand suggests that the residual muscles that were intended to move a hand through specific motions were active. While they differed on how "real" the imaginary hand felt, two subjects reported sensations of not being able to completely open or completely close the fingers of this hand. This striking similarity between the hands imagined by subjects with congenital limb deficiencies and subjects who had had traumatic amputations suggests a physiological connection between the imagined hand and the missing hand. This implies a pathway to an easy-to-use multifunction myoelectric prosthesis similar to the one that our above results show as extremely promising for traumatic amputees. The rapid development of a phantom hand by these subjects with congenital limb loss (requiring approximately an hour of motion trials followed by a short break) was a surprising and very positive, important discovery.

Discussion

This NASA/JSC-TMC project has built a myoelectric research database (an important asset that eliminates the participation barriers for new researchers); shown the potential for a major breakthrough in multifunction upper limb prosthesis control; disproved long-standing assumptions about the anatomy of congenital upper limb deficiencies; and discovered that individuals who have congenital limb loss can quickly develop a phantom limb which may be useful in prosthesis control. Prosthetics researchers are already building on this foundation to produce an artificial hand potentially useful to the approximately 80,000 Americans who have below elbow upper limb loss.

References

[1] W. H. Donovan et al. "The Next Generation Myoelectric Prostheses," Progress Report Summary for 9/30/93-11/30/94, NIH Grant 5 R01 HD 30203-02.

[2] K. A Farry, J. J. Fernandez Jr., R. Abramczyk, M. Novy, and D. J. Atkins. "Applying Genetic Programming to Control of an Artificial Arm," Myoelectric Control '97 (MEC'97), Fredericton, New Brunswick, Canada, July 21-23, 1997.

Acknowledgements

Robert Abramczyk of TIRR built the data collection system, and with Mara Novy of TIRR, coordinated data collection and documentation. Dr. Larry Kramar of University of Texas and his staff contributed radiology expertise. Kristin Farry (formerly on a National Research Council research associateship at NASA/JSC and now with Intelligenta, Inc.), Jaime Fernandez Jr. (formerly of Metrica, Inc., and now with Intelligenta, Inc.), and Jeffrey Graham (Intelligenta, Inc.) did the control system algorithm development and testing. Intelligenta, Inc., is continuing this research under SBIR funding from the National Institutes of Health and Department of Education.