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PROSTHESIS-GUIDED TRAINING FOR PRACTICAL USE OF PATTERN RECOGNITION CONTROL OF PROSTHESES

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ABSTRACT

The potential for pattern recognition to improve powered prosthesis control has been discussed for many years. One remaining barrier to at-home use of these techniques is that practical methods of user prompting during system training are lacking. Most research and development of pattern recognition systems for prosthesis control has relied on on-screen cues to prompt the prosthesis wearer during signal collection; therefore most systems require connection to a computer or external device. We have developed a method called Prosthesis-Guided Training (PGT) to address this issue. In PGT, the prosthesis itself moves through a pre-programmed sequence of motions to prompt the wearer to elicit the appropriate muscle contractions. PGT requires no extra hardware and allows wearers to retrain, refresh, or recalibrate the controller in many locations and situations. Training via PGT is self-initiated and requires only about 1 minute of the wearer's time. Furthermore, PGT provides a practical mechanism for overcoming malfunctioning or changing inputs, addresses differences in routine donning, and results in acquisition of myoelectric signals representative of those elicited during functional use. Qualitative and quantitative data acquired to investigate the efficacy of PGT suggest that it is an intuitive, effective, and clinically viable method of training pattern recognition–controlled prostheses.

BACKGROUND

The end goal of myoelectric pattern recognition for control of upper-extremity prostheses has been successful use for a prosthesis wearer in their home and community. Previously, the use of pattern recognition for real-time control of take-home myoelectric prostheses was not possible because of the limited speed and computing power of available microcontrollers. In recent years, technological advancements have eliminated this constraint.

Many additional advancements have also been made to various elements of myoelectric signal pattern recognition systems. These include refinement of classification algorithms [1-7], improved recording electrodes [8], improvements to the stability of the electrode-skin interface [9], and development of advanced prosthetic components [10-12]. In addition, conditioning of input and output signals has been shown to significantly enhance the functionality of pattern recognition control [7, 13].

Despite the progress that has been made, there is a remaining barrier to the clinical feasibility of pattern recognition prosthesis control. This barrier stems from the fact that wearers are required to train the pattern recognition system by providing the prosthesis controller with example patterns of myoelectric signals for each desired motion. These signals are used to construct the pattern classification parameters used by the control algorithm. Frequent system training is often required, as changes in environmental temperature, limb sweating, slight limb volume fluctuations, muscle fatigue, changes to socket alignment or loading, and electrode or wire failure can all cause the performance of the system to degrade significantly, resulting in a loss of function. Without a simple and intuitive method of system retraining, pattern recognition control may not find clinical acceptance [14].

SCREEN-GUIDED TRAINING

Pattern recognition systems for prosthesis control are commonly trained using visual prompts (still pictures, text, videos, etc.) displayed on a computer screen to guide the wearer through a sequence of desired movements [2, 6, 7, 13] (Figure 1a). This is what we term *Screen-Guided Training (SGT)*. The visual cues presented during SGT provide the time sequence for recording the myoelectric signals for each motion class. Because of the long-standing popularity of SGT, it is often the only technique considered for prompting the wearer during the system training of myoelectric pattern recognition systems. Successful use of pattern recognition prosthesis control in the clinical or home setting requires an approach to system training that is intuitive and requires little to no additional hardware or technological capability.

PROSTHESIS-GUIDED TRAINING

Overview

Prosthesis-Guided Training (PGT) is an easy, intuitive method of user prompting for training and calibration of pattern recognition-controlled prostheses. The concept itself is simple: to train, refresh, or recalibrate the controller, wearers press and hold a button (a 2s hold is used in the current system). This action prompts the prosthesis to begin moving through a short sequence of motions. The wearer watches and follows along by producing corresponding muscle contractions (Figure 1b). For example, as the prosthetic hand opens, the wearer contracts the muscle(s) that they use for the "hand open" command; when the arm stops or pauses between motions, the wearer relaxes and waits for the next movement. At the end of the sequence, all of the necessary myoelectric signals have been collected. The pattern classification parameters are quickly computed and the prosthesis is ready for immediate real-time use.

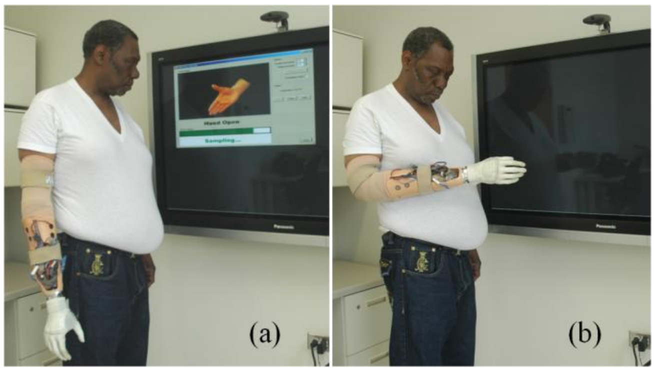

Figure 1: (a) Prosthesis wearer performing screen-guided training (SGT), note the wearer's attention to the screen images and his disregard of the static prosthesis; (b) Prosthesis wearer performing prosthesis-guided training (PGT), note the wearer's full attention to the moving prosthesis.

An additional processing step is required in PGT to compensate for the fact that wearers are not given advanced warning (such as the countdown typically used in SGT) prior to data collection, which produces a reaction delay. Because of this delay, it is not ideal to consider all of the myoelectric signals collected during device movement as valid training data. A mechanism has to be in place to determine when wearers begin/cease to produce the intended training signals. To accomplish this, the prosthesis remains stationary for a short period of time after PGT has been initiated (and after the prosthesis has returned to its "home" position) and myoelectric signals are collected while the wearer remains relaxed. This baseline level of myoelectric activity is used to calculate a threshold for the myoelectric signals generated during subsequent training movements (similar as in [1]). This thresholding technique has the added benefit that data collected when a wearer has forgotten to follow a motion is ignored. It also automatically provides additional training data for the "no-motion" category.

For PGT, the sequence of device movements for each wearer is the same each time they recalibrate. The wearer learns the sequence and timing of motions. This is likely to result in an improvement in the quality and repeatability of the elicited signal patterns over time, the comfort of the wearer with the system, and the number of training sessions required to produce satisfactory system performance.

<u>Benefits of PGT</u>

We believe there are several benefits of using PGT with a pattern recognition–controlled prosthesis:

1. Continued wear following decreased system performance

For many current myoelectric prosthesis wearers, the only course of action when a device stops working or begins to perform poorly is to take the device off and address the problem. Poor system performance can have a number of causes, such as broken or damaged parts, limb sweating, muscle fatigue, socket shift, and limb volume changes. Sometimes redonning the system can correct the problem; however, poor system performance often requires a visit to the prosthetist. No matter the issue, the device is generally removed or turned off, and this can occur at a time or place that is very inconvenient to the wearer. Because of this, some wearers may choose to leave a device at home. With PGT, many of these issues that arise can be overcome without having to take the arm off or even needing to know what caused the decreased system performance.

2. No additional hardware requirement

No external display or additional equipment is needed for PGT. When the prosthesis isn't working well (or at all), a wearer does not need to seek out a computer and display or worry about using a specific software program. Furthermore, having no computer or software means less expense to the wearer (or provider) and one less layer of technology. For system developers, graphical user interface development and software maintenance costs are greatly reduced, as is the demand for high-quality, high-bandwidth device-to-computer communication.

With the increasing popularity and presence of smart phones and personal data devices, it may be a natural fit for system developers to consider those for visual and/or audible cuing to aid in prosthetic control training and day-to-day control maintenance. Albeit more portable than a computer, using such devices still does not benefit from many of the advantages provided by PGT. Like a computer and/or display, a portable device adds cost to the system and would require the wearer to carry and maintain an additional component. Development costs with these devices are substantial, as smart phones and other devices are subject to changes outside the control of prosthesis manufacturers and developers.

3. Fast training & recalibration

With PGT, wearers can quickly get control of their device in the morning or after donning, and can also quickly retrain and recalibrate the device throughout the day. When a wearer dons their device after a period of non-use, they can quickly judge if they have acceptable control using what is stored in the prosthesis' microcontroller memory. If not, they may have donned their device slightly differently causing electrode shift, they may be more rested or fatigued, they may be performing contractions differently, or their skin conditions may have changed and these changes may affect pattern recognition control of their prosthesis. In these cases and more, PGT can help the wearer recalibrate their control and resume their activities of daily living.

The prosthesis movements that wearers follow happen consecutively with small pauses between movements, meaning the whole system can be retrained or refreshed in about one minute (a 4 degree of freedom powered prosthesis). For many prosthesis wearers that system training time is potentially much less as they may only need to retrain for a limited number of powered prosthesis motions. To wearers, this means retraining can be accomplished at almost any time and place, for example, while working in their yard, in the restroom at a dinner party, during an elevator ride, or at their desk in their place of business, etc. Each wearer's strategy for using PGT can be as unique as they are, and each can find their own way to maximize their function and capabilities. All that is demanded of the wearer is that they notice a decrease in prosthetic performance and initiate the PGT refresh of the controller.

4. Automatic normalization of dynamic range

In most conventionally controlled prosthetic systems, careful adjustment of myoelectric signal gains, thresholds, boosts, and timings must be made by a practitioner using a computer and proprietary graphical user interface. Motion Control's ProControl II has been one of the only commercially available myoelectric prosthetic devices to have an auto-calibration feature (as described in [15]). Because PGT collects the myoelectric signals for training, settings similar to these gains, thresholds, and boosts are automatically. The collected signals are used to recalibrate the wearer's dynamic signal output range for each motion every time PGT is performed. Also, wearers often elicit muscle contractions of different intensities during PGT while following movements of different speeds. If the sequence of PGT movements incorporates a range of speeds, a larger dynamic range of myoelectric signal intensities could be acquired as training data, thereby enhancing the robustness of the control system.

5. Increased system performance due to similarity of training and real-time use conditions

Compared to SGT, PGT provides more similarities between training and real-time use conditions. With SGT, the wearer and prosthesis remain stationary and the wearer's attention is focused on the display and on generating distinct muscle contractions. During real-time use, both the wearer and the arm are actively moving, and the wearer is focused on the arm and the functional task at hand. The pattern of myoelectric signals produced for a distinct movement can change depending on where the arm is positioned, whether it is moving, and whether there is a load applied to the prosthesis (e.g. if the wearer is holding a heavy object or wearing heavy clothing). With PGT, myoelectric control signals are captured while the arm is moving, producing a robust classifier that performs reliably under these varied conditions. In addition, the visual and aural attention of the wearer is focused on the arm during both PGT and real-time use. This may contribute to consistency in performance between training and testing, resulting in a more functional system.

PGT in the patient education process

Although areas have been identified where the PGT method may be considered advantageous over conventional laboratory approaches (such as SGT) for training and maintaining a myoelectric pattern recognition control system, SGT approaches may remain important for initial myoelectric controls education of the patient. We believe that PGT is a clinically applicable tool for control robustness and recalibration; however, the concept of, and initial practice with, pattern recognition control will have to happen with close guidance of the therapist and/or practitioner [16]. Part of that patient education and training can be helping the wearer learn when and how to use PGT outside of the clinic.

WEARERS' FEEDBACK

Five individuals who had undergone TMR surgery [17] had the opportunity to try PGT in the laboratory setting: three subjects with a shoulder disarticulation, and two with a transhumeral amputation. All individuals used a myoelectric prosthesis and had experience with pattern recognition systems including considerable experience with SGT. Participants gave written informed consent to participate in this study.

Wearers participated in at least two separate clinical sessions where they trained their pattern recognition-controlled multifunction prosthesis using PGT. They each performed a repetitive functional task and were allowed to recalibrate their prosthesis using PGT at their convenience. In some sessions, myoelectric signal changes and disruptions were simulated in order to investigate the efficacy of recalibration by PGT. Following these sessions, wearers provided feedback via an approved questionnaire. Table 1 reports wearers' opinions on PGT. Table 2 provides some quantitative data on how wearers would be willing to retrain or recalibrate their prosthesis.

Table 1: Subjects' average responses corresponding to 5-point Likert items (1 = "Strongly Disagree", 5 = "Strongly Agree")

Questionnaire Likert-Item	**Avg (Std)**
I would be able to use a pattern recognition-controlled prosthesis at home if I could train it myself.	5 (0)
I would be able to notice when it is necessary to re-train ("refresh") my prosthesis.	4.8 (0.4)
PGT is intuitive; the directions are clear and easy to follow.	5 (0)
PGT is tiring.	1.8 (1.2)
Having the motions presented to me in a consistent order helps me complete PGT.	5 (0)
I would feel comfortable training my prosthesis using PGT in front of people I did not know.	4.6 (0.8)

Table 2: Subjects' average responses corresponding to fill-in-the-blank questions

Questionnaire Fill-In-The-Blank Question	**Avg (Std)**
I would be willing to spend up to _____ minutes to train my prosthesis each time I put it on.	5.5 (4.9)
If it were possible, I would be willing to "refresh" the control of my prosthesis while I am wearing it up to _____ times per day.	3.2 (1.7)
If it were possible, I would be willing to "refresh" the control of my prosthesis while I am wearing it no more than about every _____ hours.	2.4 (1.6)
From my experiences with it thus far, I would be willing to do PGT ____ times in a row in an attempt to get good control back instead of taking the prosthesis off.	3.2 (1.5)

The prosthesis wearers in this study became very comfortable using PGT. The wearers provided written qualitative statements on their experience with PGT:

- "When [my prosthesis] messes up, I can retrain it without taking it off. It is more convenient."
- "I learn better following the device."
- "Helps right away just by pushing a button."
- "I feel more comfortable with it […] 'monkey see, monkey do' – how easy is that!?"

An interesting observation of the wearers' experiences with PGT arose when they had to give up the PGT and return to using SGT. Most of the wearers asked for the PGT and their recalibration "button" back.

CONCLUSION

Pattern recognition control of multifunction powered prostheses may not find clinical acceptance until a very simple and intuitive method for system training is identified. We have proposed a technique where prosthesis motions are used as the cues and prompts allowing a wearer to recalibrate their control. This PGT technique may provide benefits in helping automatically adjust the control system to the wearer by overcoming day-to-day fit and signal issues. PGT also eliminates the need for additional training tools and can be accomplished by the wearer in about one minute at any time or place they are comfortable. Wearer feedback indicates very positive acceptance and desire to have PGT available.

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