

Evaluation of electrotactile feedback schemes in combination with electromyographic control – Closing the loop

Christian K. Mortensen* and Martin A. Garenfeld*

** Undergrad. Student, School of Medicine and Health, Aalborg University*

ABSTRACT

TEXTTEXTTEXTTEXTTEXTTEXTTEXT

I. INTRODUCTION

Introduction

The loss of an upper limb can be an incredibly traumatic and life-changing event with the consequence of a significantly reduced quality of life due to restrictions in function, sensation and appearance [1, 2]. In an effort to restore pre-trauma functionality, prosthetics of various functionality and complexity have been introduced to replace the missing limb [3]. However, despite advancements in prosthetic technologies 25% of users choose to abandon their myoelectric prosthetic device [4]. A major reason for the low user satisfaction is found in the lack of exteroceptive and proprioceptive feedback provided by commercially available devices [1, 5]. Presently, merely one commercially available device (VINCENT evolution 2, Vincent Systems GmbH, DE), provides the user with feedback information of grasping force through a feedback interface [6].

The missing sensory feedback can cause the prosthetic hand to feel more unnatural and awkward [7]. Furthermore, the user mainly relies on visual feedback [7, 8], which is a need prosthetic users have shown a strong desire to decrease in order to enhance easiness and naturalness of use [9]. In a survey by Peerdeman et al. [5], it was found that secondly to receiving proportional grasp force feedback, prosthetic positional state feedback was of the highest priority. Visual independence can be achieved by providing the user with proprioceptive information through somatosensory feedback. This might facilitate the prosthetic device to be adopted by the user as an integrated part of their body, enhancing the feeling of embodiment and restoring the once physiologically closed loop [8, 10, 11, 12].

Various means of recreating the sensory feedback has been sought through either invasive and non-invasive approaches that translate information from sensors in the prosthesis to new sensory sites. Invasive methods, termed somatotopical feedback, aim to recreate the localization of the prior sensory experience by directly stimulating the nerves, which conveyed that particular sensory modality in the lost limb. This is, however, a complicated solution and multiple aspects, like long term effect, have yet to be investigated. [1, 8]. Substitution feedback utilizes various factors (pressure, vibrational, temperature, electrotactile, etc.) and their use can either be modality matched using

e.g. pressure as a substitute for grasp force [13] or non-modality matched via e.g. vibration for grasp force [14, 15]. Electrotactile feedback uses small electrical currents to activate skin afferents eliciting sensory sensations, which can be modulated in multiple parameters such as pulse width, amplitude, and frequency to convey feedback information along with the possibility of using multiple feedback channels [12]. As commercially available upper-limb prosthetics have multiple degrees of freedom (DoF's) [16] the need for multiple feedback channels is present to accommodate the amount of information which needs to be provided in a meaningful way.

In cases where two information variables are being conveyed i.e. grasping force and hand aperture using pulse rate and amplitude modulation in electrotactile stimulation [17] or pulse interval and stimulation frequency in vibrotactile stimulation [18], results have shown that one stimulator is not sufficient for users to distinguish between two modalities. In 2014, [19] Witteveen et al. provided sensory feedback of grasping force and hand aperture through a single vibrator and an array of vibrotactile actuators, respectively. Results showed that identification of stiffness for four virtual objects was around 60 %. Although the percentage was rather low, the feedback configuration proved better compared to no feedback showing that multichannel feedback helps distinguishability when conveying feedback of more than one information variable. [19] However, the use of multiple vibrotactile actuators might be less feasible and practical to implement in prosthetics, due to their size and greater power consumption compared to electrotactile stimulation.

The flexibility of electrotactile stimulation makes it desirable and its use has earlier been proven useful in cases of restoring force feedback through pressure sensors on a prosthetic hand or by the touch on artificial skin [20, 21]. However, the possibilities of electrotactile feedback have also been investigated with regards to improving prosthetic control. Strbac et al. [11] presented a novel electrotactile feedback stimulation interface, which could be used to convey information about the current state of a multi-DoF prosthesis. The system was comprised of four different dynamic stimulation patterns communicating the states of four different DoF's through a 16 multi-pad array electrode. The state of three different DoF's were communicated by altering the electrodes activated in a specific pattern. The fourth pattern communicated grasp force by modulating the stimulation frequency. Tests of the stimulation design showed that six amputees were able to recognize the stimulation pattern of the four DoF's with an average accuracy of 86 %. [11] However, it was not tested how well these stimulation patterns could be utilized

for prosthetic control

To the authors' knowledge, no one has fully closed the neural afferent/efferent loop, investigating the usability of electrotactile feedback for restoring proprioceptive aspects of myoelectric prosthetic control. Furthermore, based on the multiple parameters that can be modulated in electrotactile feedback, the question of which parameters that are most useful to convey motion state is still unanswered. The current study will, therefore, investigate which types of electrotactile feedback supports prosthetic control most usefully when conveying proprioceptive sensory feedback of the current prosthetic state. This study will present two different stimulation protocols; one based on spatial activation of differently located electrode pads, and another based on delivering different levels of amplitude.

II. METHODS

A. Experimental Protocol

To investigate the usability of the developed feedback schemes in combination with control an experiment was conducted which evaluated the usefulness of the feedback schemes when eliminating visual dependency. For this purpose 14 able-bodied subjects (12 male and 2 female - 13 right-handed and 1 left-handed with a mean age of 26.1 ± 2.4) were recruited. Included subjects signed an informed consent form and meet inclusion criteria stated in the experimental protocol, which was ethically approved by the ethical committee of Region Nordjylland, Denmark (approval number N-20150075). Each subject was introduced, trained and finally evaluated in understanding both the spatially based scheme and the amplitude based scheme. However, the order of which feedback scheme the subject would be trained/tested in was randomized. Figure 1 illustrates the chronological flow of stages in the experiment, where the first block focused on developing a subject specific prosthetic control system and the second block focused on training and evaluating the use of the sensory feedback schemes.

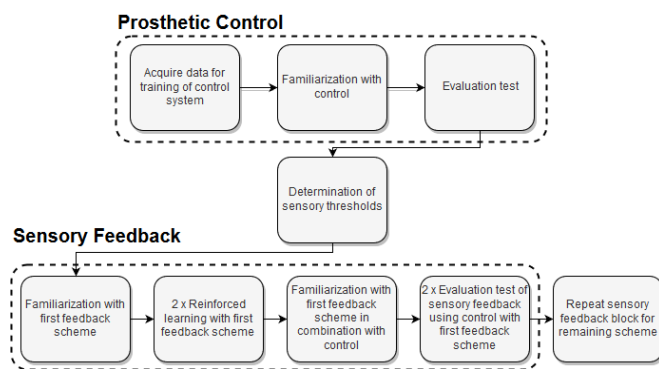


Fig. 1: Pipeline showing the stages of the experiment. The stages in the first block focused on developing and evaluating a subject specific simulated prosthetic control system. Then electrotactile sensory thresholds were determined. The second block focused on training the understanding of the feedback schemes and evaluating their use in combination with prosthetic control.

During the first block, EMG data was initially acquired and used to train a control system, which was used for a simulate prosthetic control. Subsequently, was a stage where the subject was made familiar with the control system. Finally, the achieved prosthetic control was evaluated through a target reaching test. Afterwards, a series of subjects sensory thresholds were determined for use of conveying electrotactile feedback. The subject then began the stages of familiarizing and training with a feedback scheme followed by re-familiarization of control in combination with feedback. Finally, a evaluation test of using the sensory feedback in combination for control was made. The entire sensory feedback block was then repeated using the remaining feedback scheme.

IV. RESULTS

V. DISCUSSION

VI. CONCLUSION

ACKNOWLEDGMENT

The authors would like to thank supervisors Strahinja Dosen and Jakob Lund Dideriksen for providing constructive feedback, and the School of Medicine and Health at Aalborg University for providing equipment and the facilities to complete this study. Additionally, the authors are very thankful for all the voluntary participants.

References

- [1] Jonathon S. Schofield et al. "Applications of sensory feedback in motorized upper extremity prosthesis: A review". In: *Expert Review of Medical Devices* 11.5 (2014), pp. 499–511.
- [2] Kristin Østlie et al. "Mental health and satisfaction with life among upper limb amputees: A Norwegian population-based survey comparing adult acquired major upper limb amputees with a control group". In: *Disability and Rehabilitation* 33.17-18 (2011), pp. 1594–1607.
- [3] Purushothaman Geethanjali. "Myoelectric control of prosthetic hands : state-of-the-art review". In: *Medical Devices: Evidence and Research* (2016), pp. 247–255.
- [4] Elaine Biddiss and Tom Chau. "Upper limb prosthesis use and abandonment: A survey of the last 25 years". In: *Prosthetics and Orthotics International* 31.3 (2007), pp. 236–257.
- [5] Bart Peerdeman et al. "Myoelectric forearm prostheses: State of the art from a user-centered perspective". In: *The Journal of Rehabilitation Research and Development* 48.6 (2011), pp. 719–738.
- [6] VINCENT Systems. "VINCENT EVOLUTION 2". In: <https://vincentssystems.de/en/prosthetics/vincent-evolution-2/> (2005).

- [7] D Pamungkas and K Ward. "Electro-tactile feedback system for a prosthetic hand". In: *22nd Annual International Conference on Mechatronics and Machine Vision in Practice, M2VIP 2015* (2015), pp. 27–38.
- [8] Benjamin Stephens-Fripp, Gursel Alici, and Rahim Mutlu. "A review of non-invasive sensory feedback methods for transradial prosthetic hands". In: *IEEE Access* 6 (2018), pp. 6878–6899.
- [9] Diane J. Atkins, Denise C.Y. Heard, and William H. Donovan. "Epidemiologic Overview of Individuals with Upper-Limb Loss and Their Reported Research Priorities". In: *Journal of Prosthetics and Orthotics* 8 (1996), pp. 1–11.
- [10] Heng Xu et al. "Effects of Different Tactile Feedback on Myoelectric Closed-Loop Control for Grasping Based on Electrotactile Stimulation". In: *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 24.8 (2016), pp. 827–836.
- [11] M Štrbac et al. "Integrated and flexible multichannel interface for electrotactile stimulation". In: *Journal of Neural Engineering* 13.4 (2016), pp. 1–16.
- [12] Bo Geng et al. "Evaluation of sensation evoked by electrocutaneous stimulation on forearm in nondisabled subjects". In: *The Journal of Rehabilitation Research and Development* 49.2 (2012), p. 297.
- [13] Sasha B. Godfrey et al. "Influence of Force Feedback on Grasp Force Modulation in Prosthetic Applications: a Preliminary Study". In: *Conf Proc IEEE Eng Med Biol Soc.* (2016), pp. 1–8.
- [14] Andrei Ninu et al. "Closed-loop control of grasping with a myoelectric hand prosthesis: Which are the relevant feedback variables for force control?" In: *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 22.5 (2014), pp. 1041–1052.
- [15] Muhammad Nabeel et al. "Vibrotactile stimulation for 3D printed prosthetic hand". In: *2016 2nd International Conference on Robotics and Artificial Intelligence, ICRAI 2016* (2016), pp. 202–207.
- [16] Francesca Cordella et al. "Literature Review on Needs of Upper Limb Prosthesis Users". In: *Frontiers in Neuroscience* 10.May (2016), pp. 1–14.
- [17] Ronald E. Prior et al. "Supplemental Sensory Feedback for the VA/NU Myoelectric Hand Background and Preliminary Designs". In: *Bulletin of Prosthetics Research* 101.134 (1976).
- [18] Aniruddha Chatterjee et al. "Quantifying prosthesis control improvements using a vibrotactile representation of grip force". In: *2008 IEEE Region 5 Conference* (2008), pp. 1–5.
- [19] Heidi J.B. Witteveen et al. "Stiffness feedback for myoelectric forearm prostheses using vibrotactile stimulation". In: *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 22.1 (2014), pp. 53–61.
- [20] C. Hartmann et al. "Towards prosthetic systems providing comprehensive tactile feedback for utility and embodiment". In: *IEEE 2014 Biomedical Circuits and Systems Conference, BioCAS 2014 - Proceedings* (2014), pp. 620–623.
- [21] M. Franceschi et al. "Preliminary evaluation of the tactile feedback system based on artificial skin and electrotactile stimulation". In: *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS* (2015), pp. 4554–4557.