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STUDENT REPORT

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

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1.1 Sensory Feedback Stimulation

It has been known for some time that vision alone does not provide a sufficient amount information to achieve efficient control of a prosthetic device. Hence, efforts have been put in investigating methods of providing proprioceptive and exteroceptive information of i.e. grasp strength and prosthesis orientation through the means of artificial stimulation. [1, 2] Presently, there are multiple ways of providing the user with a variety of sensory feedback. These can be divided into three categories: Somatotopically feedback, modality matched feedback and substitution feedback. [2]
This section will present general terms in sensory feedback stimulation and give a brief overview of the types of sensory feedback in order to give insight in the possibilities when providing the user of a prosthetic device with feedback.

1.1.1 Somatotopically feedback

Somatotopically feedback aims to provide the user with a sensory experience which is perceived as natural as what was felt by their missing limb, both in location and sensation. To achieve such an experience, somatotopically feedback uses invasive approaches by making use of invasive neural electrodes and targeted reinnervation. The former is known as peripheral nerve stimulation on relies on the invasive neural electrodes being interfaced with the original neural pathways preserved proximally on the residual limb. Currently, only two different types of electrodes have been exploited. One where a cuff placed surrounding a nerve fascicle and another where an electrode is implanted into the nerve fiber. But to this date, none of these methods has comprehensively studied. Targeted reinnervation also enable the possibility of stimulating the original nerual pathways from the missing limb. The corresponding sensory afferents are relocated to innervate new sites which can selectively be chosen and stimulated by non-invasive tactors. Somatotopically matched feedback is hypothesized to reduce the users cognitive burden due to its 'naturalness', facilitating increased compliance and less conscience attention. [2]

1.1.2 Modality matched feedback

In modality matched feedback the type of sensory experience which would have been felt by the missing limb is communicated to the user. For instance, when pressure is felt in the palm of a prosthetic hand by pressure sensors, a proportional amount of pressure is delivered to the user somewhere on the skin. Thus, the sensation is not matched in location, but only in sensation. Mechanotactile feedback to convey pressure information is utilized by the use of i.e. pressure cuffs or servomotors. These types of tactors are very useful for modality matched before, but have a disadvantage by being more power consuming compared to other stimulation types. [2, 3]

1.1.3 Substitution feedback

Substitution feedback methods convey information about the state of the prosthesis without regarding the type of sensation and location which would have been felt by the missing limb. Thereby, the sensory information is said to be non-physiologically representative. The feedback methods are often straightforward to implement, but leaves a greater amount of pressure on the user's ability to interpret what the feedback information represents. Often used methods for substitution feedback are vibrotactile and electrotactile feedback. [2, 3]

Vibrotactile stimulation

Vibrotactile stimulation utilizes small mechanical vibrators to convey information to a selected area of the skin activating cutaneous mechanoreceptors. This methods is most often used transfer tactile information in prosthetic grasping tasks. [2] A recognizable sensation is evoked using frequencies between 10 and 500 Hz. The sensory threshold varies between users and location, resulting in the need for specific user threshold calibration. [3]

Electrotactile stimulation

In electrotactile feedback a sensory sensation is achieved by stimulating the primary myelinated afferent nerves with an electrical current. This creates, what is often referred to as a tingling sensation. Electrotactile stimulation rely on small and lightweight electrodes to provide the electrical stimulation. When compared to other feedback methods as vibrational and pressure stimulation, which depend on heavier actuators and moving parts to provide the feedback, these properties can be seen as a drawback as prosthetic users strongly desire lightweight systems [1, 4]. Furthermore, through the use of electrotactile stimulation, multiple factors such as amplitude, pulse width, frequency and location of the stimulation can be controlled facilitating development of agile feedback schemes. This enables the possibility of varying the perceived feedback as either vibration, tapping or touch by modulating the signal waveform. The downside of using electrodes is the requirement for recalibration of sensory thresholds, pulse width and frequency to reproduce the same perceived stimulation every time the electrodes are placed on the user. In addition, interference between electrodes used for stimulation and control have been found resulting on noise the recorded EMG-signal used for myoelectric control. Concentric electrodes are able to limit the interference by limiting the spread of current. These have also been found to increase localization and perceptibility of the induced stimuli. [1, 2, 3]

1.2 State of Art in Electrotactile Feedback

As presented in section 1.1.3 electrotactile stimulation offers a series of interesting properties which can be drawn upon when conveying highly complex information. Therefore, the state of art methods using electrotactile sensory feedback in the current literature has been reviewed and will presented to ensure that the new derived feedback schemes extends recent evidence.

Multiple studies have investigated the use of electrotactile feedback regarding both how distinguishable sensations are evoked and how to convey sensory feedback in different coding schemes for improving myoelectric prosthetic control [1]. In 2015 Shi and Shen [5] investigated how subjects would perceive the effects of varying amplitude, frequency and pulse width of an electrical stimulation in various combinations. Results showed that appropriate sensations from electrical stimulation would be achieved by varying amplitude from 0.2 mA to 3 mA, pulse width from 0.2 ms to 20 ms and frequency from 45 Hz to 70 Hz. Furthermore, varying these ranges properly would make it possible to have proportionally increased grades felt by the subject. Additionally, the authors stated the importance of electrode size as stimulation through to big or to small diameters of these could result in sensations of pain or discomfort. [5]
Several studies [6, 7, 8, 9] using electrical stimulation has investigated its use in conveying grasping force/pressure feedback. Jorgovanovic et al.[6] investigated user's recognition of grip strength, in controlling a joystick controlled robotic hand, through varying the pulse width and keeping the frequency and intensity constant at 100 Hz and 3 mA, respectively. Results showed that providing electrotactile feedback improved the user's ability to move objects with the robotic hand. [6] Similar result were found by Isakovic et al. [7], who also showed that electrotactile feedback supported a faster learning than no feedback in grasp force control, and that electrotactile feedback might facilitate short-term learning. A study by Xu et al. [8] tested and evaluated different types of pressure and slip information feedback through electrotactile stimulation and compared this to visual feedback and no feedback. The study recruited 12 subjects, 6 able bodied, and provided electrotactile feedback by keeping the intensity and frequency constant and then varying the pulse width between 0 μs and 500 μs indicating changes in grasp force. In this case visual feedback was found to outperform electrotactile feedback. [8]
Pamumgkas et al.[9] also tested the use of electrotactile feedback to convey information from pressure sensors located in a robotic had. There setup used six feedback channels corresponding to a pressure sensor in each of the fingers and one in the palm. Pressure information in the sensors were giving in three discretized frequency levels of 100 Hz, 60 Hz and 30 Hz for the fingers and 20 Hz for the palm. Reported results stated that the subject's learned how to appropriately use the feedback when picking up objects of various sizes. Furthermore, the subjects reported that the preferred having electrotactile feedback accompanied by visual feedback opposed to only having visual feedback. [9] The purpose of restoring the sensation that would be experienced by touch of the skin has also been pursued in more elaborate efforts through artificial skin. Here, a grid of 64 pressure sensors were used to translate information of touch into 32 electrotactile electrodes on the

subject's arm. [10, 11]
The use of electrotactile feedback has proven useful in cases of restoring the haptic feedback through pressure sensors on a prosthetic hand or by the touch on artificial skin. However, the possibilities of electrotactile feedback has also been investigated in case of improving prosthetic control. In 2016, Strbac et al. [12] presented novel electrotactile feedback stimulation system, which could be used the convey information on the state of a multi-DoF prosthesis. The system comprised of four different dynamic stimulation patters communicating the states of four different DoF's through a 16 multi-pad array electrode, possibly restoring both proprioception and force. The state of the three of the DoF's were communicated by altering the electrodes activated in patterned fashion and the fourth DoF by modulating the stimulation frequency. Tests of the stimulation design showed that six amputees were able to recognize the four DoF's with an average accuracy of 86%. [12]

1.3 Feedback Stimulation Setup

To elicit electrotactile stimulation in this project the MaxSens stimulation device will be used along with a 16 multi-pad electrode. The following section will provide a short overview of the specification of the stimulation device and electrode.

1.3.1 Electrode

The stimulation 1×16 multi-pad electrode, which is used in this project can be seen on figure 1.1, along with dimension information. It is made of 16 circular cathodes, which each share a common long anode. The electrode consists of a polyester layer, an Ag/AgCl conductive layer and a insulation coating. The electrode to skin contact is improved by applying conductive hydrogel pads to the electrode pads. [12]

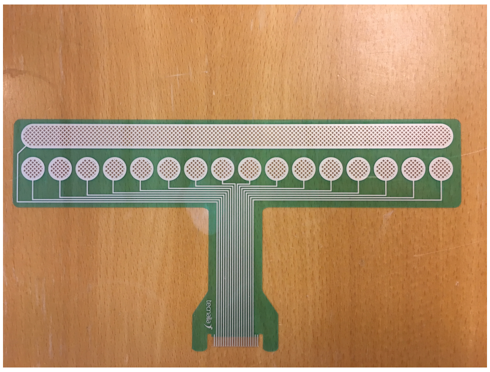

Figure 1.1: The electrode used for electrotactile feedback in this project.

1.3.2 MaxSens stimulation device

The stimulation device is made by MaxSens, Tecnalia, San Sebastian, Spain. Communication between PC and the stimulation device can be achieved either through Bluetooth or a USB connection. The device can be controlled through a series of commands. The MaxSens device allows for independent control of the 16 pads in the electrode. It generates biphasic stimulation pulses where the pulse width can be controlled within a range of 50 μs to 1000 μs with 10 μs steps, pulse rate range of 1 Hz to 400 Hz with 1 Hz steps and current amplitude range of 50 μA to 10000 μA with 0.1 μA steps. Whereas current amplitude and pulse width can be controlled independently for each pad, the pad pulse rate is set globally limiting all pads to have same pulse rate.

1.4 Electromyography

The control of a myoelectric prosthesis is based on recorded myoelectric signals. [13] Enabling the use of myoelectric signals for control of functional prosthetics requires a theoretical background knowledge of the signals origin and how it can be acquired. The following section will describe myoelectric signals and how they are acquired through the acquisition method of electromyography (EMG).

The process of executing a voluntary movement can be explained through electric potentials and the excitability of skeletal muscle fibers. The nerve impulse carrying excitation information of a voluntary muscle contraction will travel from the motor cortex down the spinal cord to a alpha motor neuron. The alpha motor neuron cell will activate and direct the nerve impulse along its axon to multiple motor endplates, which each innervate muscle fibers. [14] This initiates the release of neurotransmitters forming an endplate potential. The muscle fibers consist of muscle cells, which each are surrounded by a semi-permeable membrane. The resting potential over the membrane is held at a equilibrium, typically -80 mV to -90 mV, by ion pumps, which passively and actively control the flow of ion through the membrane. The release of neurotransmitters affects the flow through the ion pumps resulting in a greater influx of Na^+. This results in a depolarization of the cell membrane. However, only if the influx of Na^+ is great enough to create a depolarization surpassing a certain threshold, an action potential is formed. The action potential is characterized by the cell membrane potential, which changes from around -80 mV to +30 mV. After the depolarization a repolarization phase occurs and is followed by a hyperpolatization period, restoring the resting potential. The created action potential will propagate in both directions on the surface of the muscle fiber. The summation of this process and its antagonist is in summation one motor unit. Therefore, the action potential is also known as a motor unit action potential (MUAP), and it is the superposition of these across the muscle fibers, that is recorded through EMG. [14, 15]
Acquisition of EMG-signal can either be carried out through surface EMG or intramuscular EMG. The latter measures the MAUPs through needles inserted into the muscle and the former through electrodes on the skin surface. [16] Using surface EMG requires preparation of the skin surface to minimize impedance and maximize skin contact. Hence,

the skin should be clean and dry before electrode placement. Often considered is removing excess body hair or flaky skin and cleansing the area using alcohol swabs. [14, 16]

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