A Design Space for Electrical Muscle Stimulation Feedback for Free-Hand Interaction

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Abstract
Free-hand interaction becomes a common technique for interacting with large displays. At the same time, providing haptic feedback for free-hand interaction is still a challenge, particularly feedback with different characteristics (i.e., strengths, patterns) to convey particular information. We see electrical muscle stimulation (EMS) as a well-suited technology for providing haptic feedback in this domain. The characteristics of EMS can be used to assist users in learning, manipulating, and perceiving virtual objects. One of the core challenges is to understand these characteristics and how they can be applied. As a step in this direction, this paper presents a design space that identifies different aspects of using EMS for haptic feedback. The design space is meant as a basis for future research investigating how particular characteristics can be exploited to provide specific haptic feedback.

Author Keywords
Electrical Muscle Stimulation, Haptic Feedback, Free-hand Interaction.

Introduction
Since full body tracking systems, such as the Microsoft Kinect, have entered the mass market, mid-air interaction in front of (large) displays has become commonplace [2].

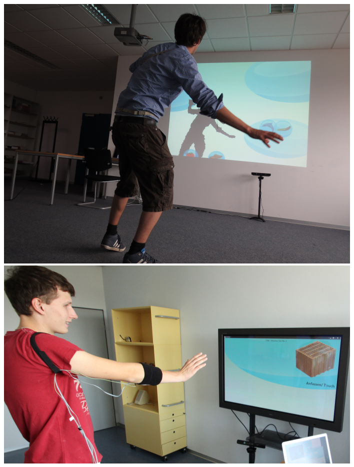

Figure 1: Free-hand interaction with haptic feedback: A user receives haptic feedback when approaching an object on the screen.

Figure 2: An EMS feedback system: A user wearing a mobile EMS feedback system that is attached to the forearm.

This way of interaction has many use cases beyond home entertainment and gaming. Surgeons can control information displays (e.g., showing an X-ray), people with disabilities can be supported in their working environments, and people can manipulate virtual objects over a distance on large displays (Figure 1).

In many of these cases, haptic feedback is beneficial, for example, to indicate that an action has been performed. The feedback can stimulate a number of different nerves and receptors in the human skin, including free and sensory hair nerves as well as receptors for cold, heat, touch, pressure, and pain [5]. In contrast to a mobile phone that can provide haptic feedback through vibration, haptic feedback is difficult for free-hand interaction where users are neither touching the screen nor holding a device. One solution is gloves, which, however, imply a burden and are inappropriate in summer. We aim to make free-hand interaction [7] more realistic and convincing by providing haptic feedback in a way that is easily applicable in daily life.

As a solution we envision small, wearable devices, such as wristbands, that can emit EMS feedback. Such devices can be carried by the user and are available in everyday life. EMS offers a particularly wide range of different strengths and qualities of haptic feedback with reasonable power consumption and device size and does not require any mechanics. This makes it a highly suitable technology for free-hand interaction. The wrist and the lower arm are a particularly well suited body positions for applying haptic feedback in free-hand interaction. Wristband devices are already popular for life logging applications (e.g., Nike+ Fuelband[1] or Jawbone Up[2]). Such haptic feedback methods can be used for assistive systems, where users do not hold a controller in hands. That enhances the user's capability to interact with other physical objects while wearing the feedback system and not feel strange in social situations.

A number of devices that incorporate EMS are already commercially available, such as massage systems (e.g., ProRelax[3]) or fitness systems (e.g., Miha Bodytec[4]). EMS has also been used in several research systems. PossessedHand [10] is a device for controlling finger-joints by EMS. The authors show that electrical feedback is suitable for mixed reality, navigation, and learning to play instruments. Lopes and Baudisch [6] use EMS in a mobile game to generate force feedback. They investigate the length of electrical feedback signals and test the amount of force a user can provide. Pfeiffer et al. [8] use EMS feedback for interacting with large displays in public space. They compered EMS feedback to vibrational feedback in free-hand interaction with virtual objects [9].

Following the notion of Nancel et al. [7], we use the term *free-hand interaction* to describe interactions based on mid-air gestures [1, 3] that do neither need a physical connection to the display nor a handheld controller. Free-hand interactions are characterized by not limiting the degree of freedom for hand movements or the perception of tactile stimuli.

In this paper, we contribute a design space for EMS as haptic feedback. We present a number of dimensions that need to be taken into account when designing EMS-based haptic feedback systems.

[1] Nike+ Fuelband: www.nike.com/FuelBand_SE
[2] Jawbone Up: www.jawbone.com/up/international

[3] ProRelax: www.prorelax.com
[4] Miha Bodytec: www.miha-bodytec.com

Design Space for Haptic Feedback

The following design space focuses on the essential parameters for creating highly variable feedback for covering different situations. The dimensions of the design space are based on a literature review of EMS feedback systems.

Sensing capabilities

The haptic sensing capabilities are based on the different nerves in the skin, tissue, and muscle that are stimulated by touch, pressure, and heat. For electrical impulses of a duration longer than 10 ms a current of 10-20 mA stimulates only the sensory nerve fibers, of 20-40 mA in addition stimulates the motoric nerve fibers, and of more than 40 mA also stimulates the pain nerve fibers [4]. Depending on the body position the density of nerves varies.

Application of Current

The current required to produce haptic feedback can be induced in different ways. Actuators could be placed onto the skin (e.g., water bath or electro pads (cf., Figure 2)), into the skin (e.g., through needles), or in the body (e.g., through cardiac stimulator). The non invasive skin electrodes are mostly used. The size of the conductive area and the conductivity of the electrodes define the amount of current that gets through the skin. As more current is applied more skin receptors are stimulated. Dry and thick areas of the skin have higher resistance than thin and wet skin areas.

Impulse Characteristics and Frequency

When it comes to applying the current, the following characteristics have an influence on the haptic perception: the strength of the applied current, the applied duration, the impulse form, the impulse frequency, and the impulse duration. The form of the impulse is mostly follow the characteristics of a sine wave, a square wave, or a sawtooth wave. Furthermore, EMS typically uses frequencies between 1 Hz and 1 kHz. With short impulses of 100 μs the skin resistance decreases and with long pulse durations the skin resistance increases. For contacting a muscle, typically impulse durations up to 400 μs are used.

Position on the Body

In cases where EMS feedback is applied through a device on the user's body, a number of different positions are possible. These include the fingers, the forearm, the upper arm, the torso, the head, the face, the legs, and the feet. Applying feedback to each of these parts of the body works differently well. In case of actuating a limb, the size of the muscle and the position to other muscles has an impact on the provided force and precision of the actuation (singe muscle vs. muscle group). When there are no muscles under the stimulated area only tactile feedback can be provided. The choice for a position usually depends on the action for which feedback should be applied (playing football vs. grabbing something with the hands – cf., Figure 1 bottom).

Feedback Pattern and Content Characteristics

EMS-based feedback can be applied different patterns. In its easiest form, the feedback is simply switched on and off. Furthermore, it may increase/decrease over time or it may follow a (complex) rhythm. With those pattern content characteristics can be simulated through the feedback. This is in many cases a continuum, such as simulating a soft or hard surface, a smooth or rough surface, or a slow or fast movement. For example, a flat surface can be simulated with a continuous feedback and a rough surface with an alternating feedback.

User Input

The feedback that is provided to the user depends on the input that is performed to achieve a realistic feedback. There are several input method that benefit from haptic feedback such as mid-air gestures (e.g., touch, grab, or punch) or two-dimensional touch gestures (e.g., pinch).

Discussion and Conclusion

The use of EMS feedback is still in its infancy. We believe that in certain cases, such as assistive augmentation, EMS feedback can enrich mid-air interaction. EMS provides a wide range of different feedback strengths and characteristics. The feedback system is placed on the muscle (e.g., the forearm) but the feedback is perceived at the end of the muscle (e.g., the hand). Hence, feedback can be triggered at a position that is different from that of the device. As a result, feedback can be applied in a more socially acceptable way and without restricting interaction with the hands.

Our work is a first step in systematically analyzing and assessing the design space. By presenting the design space, we identified a number of parameters and values that should to be considered when designing EMS feedback. As future work we aim to draw upon the design space by investigating the impact of different patterns – including patterns of varying impulse lengths, increasing strength, rhythmical impulses, and different shapes of the signal. Furthermore, we consider a combination of EMS feedback with other haptic feedback methods, such as vibration, to be promising.

Acknowledgments

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