RESTORING SENSORY FEEDBACK IN ROBOTIC PROSTHESES

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The amputation of a limb is devastating and it dramatically decreases the quality of life of affected persons. Modern-day robotic prostheses can restore some of the missing motor functions; however, none of the mainstream commercial systems provides explicit sensory feedback to their users [1]. Restoring feedback would allow persons with amputation to "feel" their bionic limbs, which can improve utility as well as facilitate the feeling of embodiment. The feedback can be provided by delivering tactile stimulation using invasive and non-invasive methods [2]. To this end, a prosthesis is equipped with sensors measuring the state of the system (e.g., grasping force, joint angles), the measured information is translated into tactile stimulation profiles, which are then delivered to the biological sensory structures still spared after amputation (e.g., peripheral nerves, the skin of the residual limb).

The methods for feedback restoration are presently in the focus of the research efforts of many groups. In the present lecture, we will briefly summarize the state of the art, and then present the latest developments of our group (Neurorehabilitation Systems, Aalborg University, Denmark). More specifically, we will show how multichannel electrotactile stimulation can be employed to convey to the user the state of advanced multifunctional prostheses. We will discuss different approaches for the translation of feedback variables into stimulation profiles (i.e., encoding schemes) eliciting sensations that are perceivable and easily interpretable [3]. This will include representative implementations of artificial exteroceptive (e.g., grasping force and contact) and proprioceptive (e.g., hand aperture and wrist rotation) feedback. To this aim, flexible electrodes that integrate an array of conductive pads are placed around the residual limb (forearm) and the feedback information is delivered by activating different pads as well as by modulating the stimulation parameters (e.g., pulse amplitude, pulse width, and/or frequency). Such spatiotemporal stimulation profiles elicit sensations that move across residual limb and change in quality. The "moving" sensations are particularly convenient to convey proprioception while changing the quality (e.g., intensity and/or frequency) can be used to transmit the grasping force and contact information. Importantly, the electrotactile feedback can be delivered using compact hardware, which makes this approach convenient for integration into a prosthetic socket [4]. One example of such a compact system, which allows simultaneous tactile stimulation and recording of muscle activity, will be presented as an interface that can provide both control and feedback, hence a closed-loop connection between the user and his/her bionic limb. We will also illustrate methods that can be used to assess the impact of feedback in terms of performance and user experience, and report our recent results. This will show that feedback is a multifaceted phenomenon and that its benefits depend on several factors, including the nature of the task, level of training, and user experience [5].

Finally, we will close the lecture by showing our recent work on the use of matrix electrodes that integrate many conductive pads to provide spatially distributed stimulation [6]. This interface can be used to convey feedback from an electronic skin covering the prosthetic hand. The electronic skin is a flexible sheet comprising a matrix of tactile sensors, detecting mechanical interaction between hand and object. The information measured by the skin (contact pressure) can be delivered to the human subject by activating the corresponding pads on the electrotactile matrix placed over the residual limb [7]. A combination of electronic skin and matrix electrotactile stimulation can be used to restore spatially distributed tactile feedback to the user of a prosthesis, mimicking thereby the natural feedback provided by the biological hands.

Keywords: upper-limb prostheses, artificial sensory feedback, electrotactile stimulation, grasping force, proprioception, electronic skin, matrix electrodes

References

1. Sensinger J W and Dosen S 2020 A Review of Sensory Feedback in Upper-Limb Prostheses From the Perspective of Human Motor Control Front. Neurosci. 14
2. Bensmaia S J, Tyler D J and Micera S 2020 Restoration of sensory information via bionic hands Nat. Biomed. Eng.
3. Garenfeld M A, Mortensen C K, Strbac M, Dideriksen J L and Dosen S 2020 Amplitude versus spatially modulated electrotactile feedback for myoelectric control of two degrees of freedom J. Neural Eng. 17 046034
4. Garenfeld M A, Jorgovanovic N, Ilic V, Strbac M, Isakovic M, Dideriksen J L and Dosen S 2021 A compact system for simultaneous stimulation and recording for closed-loop myoelectric control J. Neuroeng. Rehabil. 18 87
5. 2018 The clinical relevance of advanced artificial feedback in the control of a multi-functional myoelectric prosthesis. J. Neuroeng. Rehabil. 15 28
6. Franceschi M, Seminara L, Dosen S, Strbac M, Valle M and Farina D 2017 A System for Electrotactile Feedback Using Electronic Skin and Flexible Matrix Electrodes: Experimental Evaluation IEEE Trans. Haptics 10 162–72
7. Abbass Y, Saleh M, Dosen S and Valle M 2021 Embedded Electrotactile Feedback System for Hand Prostheses using Matrix Electrode and Electronic Skin IEEE Trans. Biomed. Circuits Syst. (in press)