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An SEMS-Based Force Feedback Device for Teleoperation and Rehabilitation.

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Electrical Muscular Stimulation (EMS) is a promising tool for scenarios where force feedback is required either with the goal of causing a movement in a user with impaired motor control or of providing haptic cues to a healthy user in, e.g., teleoperation or applications in virtual reality. An EMS system can be much more energy efficient than an exoskeleton, and can furthermore preserve muscular activity in users unable to voluntarily move. In rehabilitation, per- or subcutaneous electrodes are often the preferred solution if precision and selectiveness have priority. However, if surgical implantation is undesirable, surface electrodes can also be used. These are, however, subject to many issues with regard to the precision attainable when stimulating a given muscle group. Because of the distance from inner muscles and the presence of fat/connective tissue, surface EMS (sEMS) can lead to the unwanted stimulation of untargeted motor neurons. Furthermore, when using surface electrodes it is impossible to individually stimulate deeper muscle groups without also stimulating the superficial ones. Moreover, most solutions known from literature seem to address very specific joint movements.

In this article we introduce the MyoCeption: a wearable, wireless sEMS-based force feedback device able to provide stimulation currents on up to 10 independent channels with 16-bit amplitude resolution. This stimulation is computed by a piece of proprietary software based on the current pose of the user applied to a real-time musculoskeletal model and impedance control, which can be tuned via twitch-based calibration. This technique consists in passing a sharp stimulation signal across an individual electrode pair and measuring the angular velocity of the consequent twitch in direction and magnitude. Based on this technique the system calibrates its own musculoskeletal model, as well as the weights modulating the intensity of the stimulation applied to each electrode pair.

References: Lopes, P., You, S., Ion, A., & Baudisch, P. (2018, April). Adding force feedback to mixed reality experiences and games using electrical muscle stimulation. In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (pp. 1-13)., Katoh, M., Nishimura, N., Yokoyama, M., Hachisu, T., Sato, M., Fukushima, S., & Kajimoto, H. (2013, March). Optimal selection of electrodes for muscle electrical stimulation using twitching motion measurement. In Proceedings of the 4th Augmented Human International Conference (pp. 237-238).,

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An EMS-Based Force Feedback Device for Teleoperation and Rehabilitation

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ABSTRACT

Electrical Muscular Stimulation (EMS) is a promising tool for scenarios where force feedback is required either with the goal of causing a movement in a user with impaired motor control or of providing haptic feedback to a healthy user in, e.g., teleoperation or applications in virtual reality. An EMS system can be much more energy efficient than an exoskeleton, and can furthermore preserve muscular activity in users with impaired motor control. In rehabilitation, per- or subcutaneous electrodes are often the preferred solution if precision and selectiveness have priority. However, if surgical implantation is undesirable, surface electrodes can also be used. These are, however, subject to many issues with regard to the precision attainable when stimulating a given muscle group. Because of the distance from inner muscles and the presence of fat/connective tissue, surface EMS (sEMS) can lead to the unwanted stimulation of untargeted motor neurons. Furthermore, when using surface electrodes it is impossible to individually stimulate deeper muscle groups without also stimulating the superficial ones. Moreover, most solutions known from literature seem to address very specific joint movements. In this article we introduce the MyoCeption: a wearable, wireless sEMS-based force feedback device able to provide stimulation currents on up to 10 independent channels with 16-bit amplitude resolution. This stimulation is computed by a piece of proprietary software based on the current pose of the user applied to a real-time musculoskeletal model and impedance control, which can be tuned via twitch-based calibration. This technique consists in passing a sharp stimulation signal across an individual electrode pair and measuring the angular velocity of the consequent twitch in direction and magnitude. Based on this technique the system calibrates its own musculoskeletal model, as well as the weights modulating the intensity of the stimulation applied by each single electrode pair.

Keywords: EMS, force feedback, wearable, rehabilitation.

INTRODUCTION

The MyoCeption in this experiment was used in conjunction with the BodyRig, an IMU-based body tracking system. Figure 1 shows the full setup as well as a detailed breakdown of the MyoCeption. The system is able to operate an automatic calibration of the underlying musculoskeletal model by probing the reaction of the user to a sharp stimulation current (see Fig. 2 right).

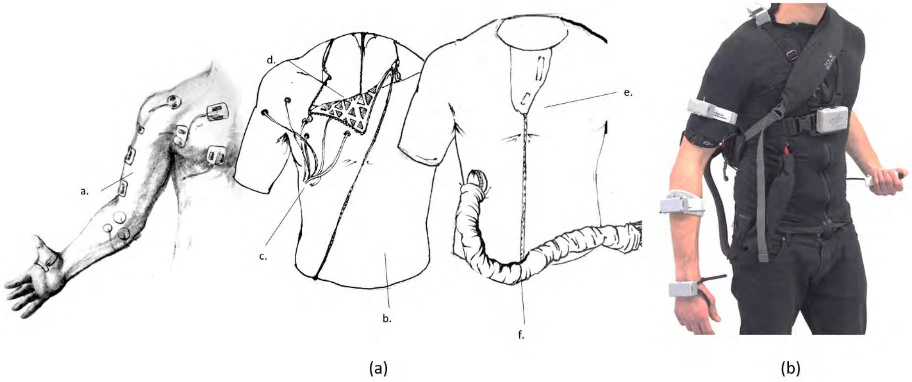
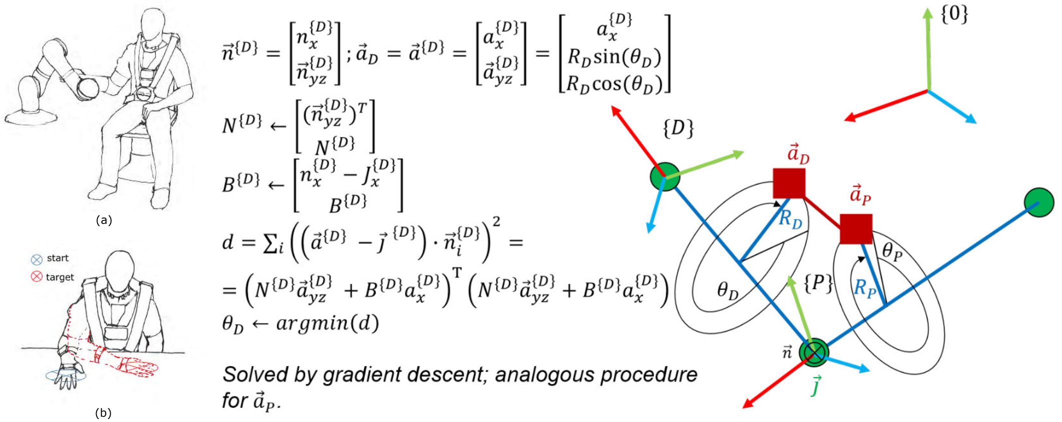


Figure 1: a: MyoCeption system elements. In the picture, from left to right, one can see the surface electrodes applied to the user's skin, which are fitted with Velcro hooks on the outside (a). The inner compression jacket (b) features holes (c) to run the electrode cables through, and is fitted with Velcro loops on the inside, so as to ease electrode application (d). The outer jacket (e) groups the cables in a single umbilical (f) connected to the control electronics, and provides further compression. **b:** Picture of the full setup as worn by a user.

METHODS



$$\vec{n}^{\{D\}} = \begin{bmatrix} n_x^{\{D\}} \\ \vec{n}_{yz}^{\{D\}} \end{bmatrix}; \vec{a}_D = \vec{a}^{\{D\}} = \begin{bmatrix} a_x^{\{D\}} \\ \vec{a}_{yz}^{\{D\}} \end{bmatrix} = \begin{bmatrix} a_x^{\{D\}} \\ R_D \sin(\theta_D) \\ R_D \cos(\theta_D) \end{bmatrix}$$

$$N^{\{D\}} \leftarrow \begin{bmatrix} (\vec{n}_{yz}^{\{D\}})^T \\ N^{\{D\}} \end{bmatrix}$$

$$B^{\{D\}} \leftarrow \begin{bmatrix} n_x^{\{D\}} - J_x^{\{D\}} \\ B^{\{D\}} \end{bmatrix}$$

$$d = \sum_i \left(\left(\vec{a}^{\{D\}} - \vec{j}^{\,\{D\}} \right) \cdot \vec{n}_i^{\{D\}} \right)^2 =$$

$$= \left(N^{\{D\}} \vec{a}_{yz}^{\{D\}} + B^{\{D\}} a_x^{\{D\}} \right)^{\mathrm{T}} \left(N^{\{D\}} \vec{a}_{yz}^{\{D\}} + B^{\{D\}} a_x^{\{D\}} \right)$$

$$\theta_D \leftarrow argmin(d)$$

Solved by gradient descent; analogous procedure for $\vec{a}_P$.

Figure 2: Left: Experimental setups to characterize the system. **a:** the user's torso is immobilized and their forearm is coupled to a force/torque sensing machine (such as a robotic arm fitted with torque sensors at the joints or a multidimensional load cell). **b:** The user sits at a table or a surface which sustains most of the arm's weight. The MyoCeption is used to induce movement towards a target hand position on the table starting from a randomized hand position. **Right:** Calibration procedure: the most likely position of the stimulated muscle group's anchor points is computed by analyzing the maximal angular velocity vector of the twitch resulting from a sharp stimulation current.

RESULTS AND FUTURE WORK

The system can be used to exert forces on the user and many possible control structures can be tested. A comparison of calibrated vs not calibrated system showed a significantly smoother movement when using the calibrated system ($t(12) = 2.2720, p < 0.05$) during the tabletop experiment (see Fig. 2 left b). The metric used was the spectral arc length (SPARC) index (calibrated: $-5.4942(2.6726)$, not calibrated: $-13.7934(9.9898)$). Several questions remain open:

- Determination of the optimal muscle recruitment strategy is still open. At the moment, the control system simply selects the nearest neighbour among the muscle groups on a certain joint in terms of elicited torque compared to the needed torque.
- While impedance control seems to be promising, other control architectures would be conceivable and could potentially be a better fit for certain tasks.
- For the case of impedance control, determination of task-specific stiffness, dampening and integration matrices is a non-trivial problem.
- For usage in rehabilitation, an adequate intent prediction solution has yet to be found.
- Naturally, tests in a clinical setting have to be performed to assess the potential value of the system as an element in a task-oriented rehabilitation program.

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