Modular FES-hybrid ortosi for individualized setup of BCI controller motor substitution and recovery

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Abstract. In this paper, the components of a modular FES-hybrid orthosis are presented. The hybrid-orthosis aims at 1. the restoration of a lost hand grasp and restricted elbow movements in high spinal cord injured individuals and 2. the recovery of functions in the sense a BCI-controlled rehabilitative training in stroke patients. The novel device can be individually adapted to different users and application scenarios and supports a variety of input modalities for control including a hybrid-BCI. This approach aims at a personalized setup of the device, selecting only those modules, which are needed to fulfill a given user need.

Keywords: Functional Electrical Stimulation, BCI, Individualization, Modular, Orthosis, Motor

1. Introduction

The application work packages 2 “motor substitution” of the European project TOBI (FP7224631) aims at the substitution of a lost grasp and elbow movement in spinal cord injured (SCI) individuals by the application of an arm neuroprosthesis based on Functional Electrical Stimulation (FES) together with orthotic components [Millán et al, 2010]. The same neuroprosthesis is been foreseen to be used as part of a BCI controlled rehabilitative training for upper extremity motor recovery of stroke patients. For matching the individual needs of several user groups and different application scenarios a prototype of a modular FES-hybrid orthosis has been developed.

2. Hardware of the modular FES-hybrid orthosis

The main components of the modular orthosis (see Figure 1) consist of an in flexion direction selflocking, electrically delockable elbow joint to prevent excessive muscle fatigue and self-adhesive gel FES electrodes in combination with a multichannel electrical stimulation device (Motionstim, Krauth & Timmermann, Hamburg). Its dedicated firmware allows for autonomous use and implementation of shared control principles.
To overcome the not smoothly executed grasp patterns during FES stimulation, a passive hand orthosis has been developed [Nathan, 1990]. The goal of this orthosis is to evenly synchronize the grasping movements and applied forces on all fingers, allowing for naturalistic gestures and functional grasps of everyday objects. Furthermore, the orthosis can be upgraded with a wrist orthosis for wrist joint stabilisation. In order to further improve the FES-hybrid orthosis, first test sessions in a high tetraplegic SCI individual with no hand-, weak elbow flexion and moderate shoulder function have been performed. During these tests it became obvious that in patients with restrictions of shoulder abduction a certain degree of pronation of the wrist is necessary to perform basic activities of daily living, namely eating and drinking. Therefore, according to the concepts used in functional tendon transfer surgery [Hentz et al, 2002] the pronation movement of the wrist has been coupled via a mechanical link to the elbow flexion movement. This feature increases the usability of the orthosis, especially for the purpose of independent eating and drinking.

3. Individualization of the modular FES-hybrid orthosis and its user interface

The orthosis will be applied in different scenarios and will be worn by different users. To match their individual needs, the orthosis has been developed in a highly modular way. This approach aims at equipping the user only with those modules (hard- and software) he or she needs.

For example, for restoration of the hand function, only the corresponding forearm components for stimulation of hand and finger muscles have to be integrated. In case a support of elbow movements is necessary the module for the upper arm incorporating additional FES electrodes in combination with the de-/lockable elbow joint can be provided.

Furthermore the orthosis supports a variety of input modalities for control. Binary signals, e.g. originating from a BCI or mechanical switches, can be used as well as analog signals, recorded from myoelectric (EMG), angle or bend sensors.

In the configuration of exclusive hand control, one analog channel is sufficient to adjust the degree of hand opening and closing. If a paralyzed user has unrestricted control over his contralateral shoulder a shoulder position sensor can be employed as a control interface.

If both hand and elbow modules have been integrated in the orthosis, a digital command signal (for example, originating from a MI-BCI) has to be included that enables the user to route the analog signal of the shoulder position to control either the hand or the elbow.

Additionally, a dedicated software for the “Motionstim” stimulator has been developed to be applicable in a rehabilitative setting for functional motor recovery after stroke. The software provides the definition of grasp states based on predefined pulse widths for each channel. For switching between the opening and closing posture of the hand only one binary trigger signal is necessary. The pulse widths range from 50 - 400µs, whereas shorter pulse widths are used in case of pain. The stimulation frequency ranges between 16 -20 Hz and the current is set up to a level, in which a sufficiently strong muscle contraction and function occurs. All parameters are determined for every patient individually.

4. Conclusion

A modular FES-hybrid orthosis has been developed for restoration of reaching and grasping function in high-level lesioned spinal cord injured subjects and for application in a rehabilitative training for stroke patients. The advantage of the modular approach is that it can be individually adapted to the needs of different patients and application scenarios. Care has been taken to allow for coupling the orthosis control to several user interfaces including the hybrid BCI-approach. The orthosis is currently being evaluated in users with different levels of impairment and different scenarios.

References