

Integration of an EMG-based NMES controller with a passive exoskeleton to support daily upper limb activities

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Abstract

MUNDUS is an assistive framework for recovering interaction capability of severely impaired people based on upper limb motor functions. Within this project, the present work aimed at integrating a commercial passive exoskeleton for weight support with an EMG-controlled neuroprosthesis for hand-to-mouth movements. Being the stimulated muscle the same from which the EMG was measured, first it was necessary to separate the volitional EMG from the stimulation response. Thus, an adaptive filter to remove the M-wave was developed. Then, an EMG integration-based controller was designed: when the volitional EMG exceeded a pre-defined threshold, the pulse width ramped up until the maximal value and was kept constant until the volitional EMG dropped below an inferior threshold. The operation of the control system was tested on one healthy volunteer, who was asked to perform some hand-to-mouth movements, supported by both the exoskeleton and the EMG-controlled neuroprosthesis. Preliminary results showed that the filter was able to discriminate between increasing values of volitional EMG, while the controller operation reflected the subject's intention. The study demonstrated the feasibility of an EMG-controlled neuroprosthesis for daily upper limb support on healthy subjects, providing a first step forward towards the development of the final MUNDUS platform.

Keywords: neuroprosthesis, EMG, assistive device, upper limb support.

Introduction

MUNDUS is an assistive device for recovering interaction capability based on upper limb functions. Its main concept is to exploit any residual control of the user, being suitable for long term use in daily activities. The target pathologies are neurodegenerative and genetic neuromuscular diseases, and high level Spinal Cord Injuries. MUNDUS is a modular platform where different sensors are processed to provide arm/hand motions by using different actuators. Sensors, actuators, and control solutions adapt to the level of severity or to the progression of the disease.

Within this framework, the present work aimed at integrating a commercial exoskeleton with an EMG-controlled neuroprosthesis to support hand-to-mouth movements.

The EMG detection during Neuro Muscular Electrical Stimulation (NMES) is challenging as large measurement artifacts occur [1]. When an EMG signal without artifacts is available, the EMG comprises both the stimulation response (M-wave) and the volitional EMG. Fig. 1 shows an example of EMG acquired during voluntary contractions of the biceps, simultaneously stimulated at constant values of current amplitude and pulse width. During isometric contractions (Fig. 1, panel (A)),

the M-wave is almost repeatable, being the stimulation parameters constant. Thus, simple filter solutions, such as the comb filter, were proposed in literature to extract the volitional EMG in isometric conditions [2]. During dynamic contractions (Fig.1, panel (B)), the M-wave strongly changes, making the design of an algorithm to detect the volitional EMG more challenging. In the present work, we developed an adaptive filter [3] to detect the very low volitional EMG acquired during dynamic contractions supported by a passive exoskeleton for weight relief. The resulting volitional EMG was used as an input of an EMG integration-based controller for supporting hand-to-mouth movements of severely impaired people.

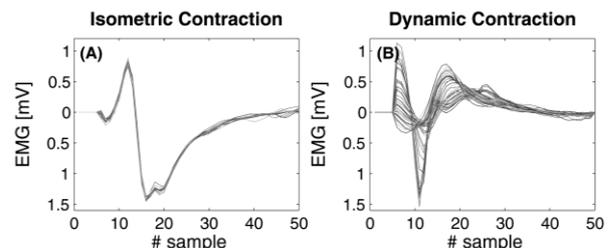


Fig. 1. EMG signals (without stimulation artifacts) acquired in 10 stimulation periods during isometric (panel (A)) and dynamic (panel (B)) contractions.

Methods

Experimental setup

Fig. 2 shows the experimental setup. A PC running Scilab/Scicos under real-time Linux (RTAI) was used to acquire the data and control the RehaStim™ (Hasomed GmbH, Magdeburg, Germany) stimulator (stimulation frequency of 20 Hz). The EMG was acquired with a sampling frequency of 1 kHz using a commercial polygraph (Porti™, Twente Medical System International, Twente, Netherlands). The EMG electrodes were placed 1 cm apart on the belly of the biceps, within the two stimulation electrodes, perpendicular to the muscle fibers as suggested by [2]. A detailed picture of the electrodes placement is reported in Fig. 2. The subject's arm was fixed to the ArmeoSpring (Hocoma AG, Volketswil, Switzerland).

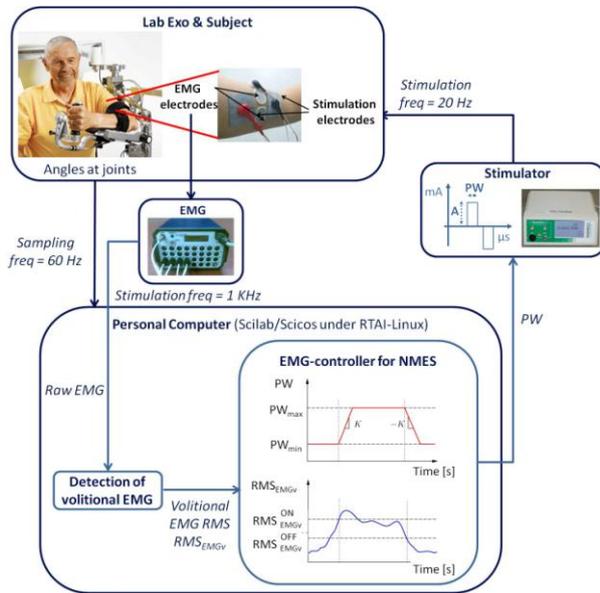


Fig. 2: Experimental setup

Design of the closed-loop control system

The closed-loop control system consisted of two main parts: (1) the detection of the volitional EMG; (2) the EMG-control system for NMES.

To estimate, every stimulation period (50 ms), the intensity of the volitional muscle activity from the EMG, we first applied a 3rd order Butterworth high pass filter (cut off frequency of 5 Hz) to remove the offset of the EMG signal; the final 25 ms of the EMG were extracted (windowing); then, an adaptive filter was applied to the final 25 ms of the EMG data in order to remove the stimulation response. The adaptive filter was implemented following the algorithm described by Sennels et al [3]. This filter is based on the assumption that the M-wave is a deterministic signal with almost constant shape and stimulation-dependent

amplitude. Assuming furthermore, that the volitionally induced-EMG is a pseudo-random signal, the current M-wave can be predicted as a linear combination of 6 previous M-waves. To find the best prediction of the current M-wave, a least squares problem has to be solved in order to minimize the output energy of EMG_v with respect to the filter coefficients. To estimate the voluntary activity, the RMS of the filter output was computed every 50 ms.

Afterwards, the voluntary activity estimation became the input of the EMG-controller for NMES that gave as output the stimulation pulse width (PW) to be delivered to the biceps. The controller had a piece-wise linear input-output relationship as shown in Fig. 2: when the volitional EMG exceeded the superior threshold, RMS_{EMGv}^{ON} , the pulse width ramped up with a slope of K until the maximal value, PW_{max} , was reached. Then, the stimulation level was kept constant until the recorded volitional EMG dropped below the inferior threshold, RMS_{EMGv}^{OFF} . At this event, the pulse was reduced with a slope of $-K$ till PW_{min} .

Experimental protocol

The operation of the control system was validated through two sets of experimental trials performed by one healthy volunteer: the first one aimed at evaluating the discrimination ability of the filter; the second one at testing the controller.

1) To evaluate the discrimination ability of the filter the subject was asked to produce a sequence of elbow flexions starting from a rest position in which the elbow was at about 160° of flexion (about 170° is the position in which the elbow is fully extended) and ending close to the mouth. Ten repetitions of elbow flexion were carried out in 3 different conditions: (1) without any load (2) holding a 1 kg weight, (3) holding a 2 kg weight.

2) To test the controller operation, the subject was asked to perform the same movement without any load in 2 modalities: maintaining the voluntary contraction throughout the hand-to-mouth movement, and releasing the voluntary contraction soon after NMES started to be delivered.

Before the beginning of the two sets of trials, the stimulus intensity was set at a value producing visibly good muscle contraction, whereas the values of PW_{min} and PW_{max} were fixed at 0 μ s and 450 μ s, respectively.

A fast calibration procedure was carried out to estimate RMS_{EMGv}^{ON} and RMS_{EMGv}^{OFF} . This procedure consisted of a first part during which the subject was asked to contract the biceps voluntarily without delivering any stimulation; then, the

stimulation was switched on and the subject was asked to relax the muscle.

Results

A healthy subject was involved in the experimental trial. The stimulus amplitude was fixed at 15 mA.

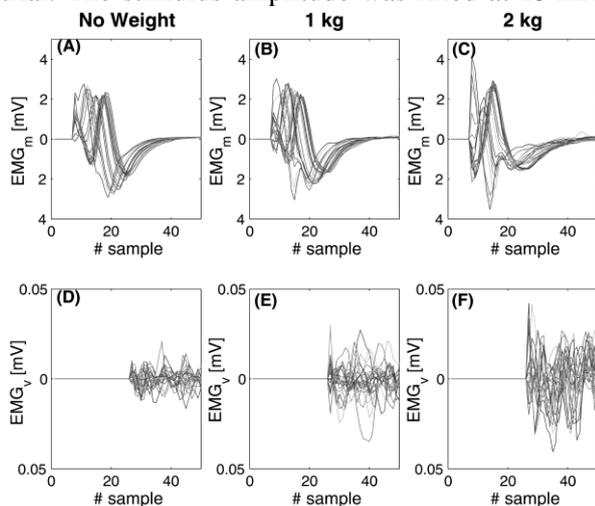


Fig. 4. Performance of the adaptive filter during the three experimental conditions: without any load (panels (A) and (D)); with a 1 kg weight (panels (B) and (E)); with a 2 kg weight (panels (C) and (F)). Panels (A), (B), and (C) show the recorded EMG and panels (D), (E), and (F) the correspondent volitional EMG extracted.

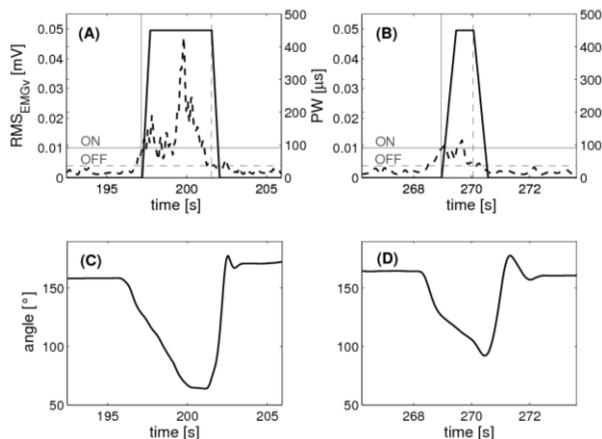


Fig. 5. Performance of the EMG-control system for NMES during the two modalities: maintaining (panels (A) and (C)) and not maintaining (panels (B) and (D)) the voluntary contraction. Panels (A), and (B) show the RMS of the volitional EMG (dashed line) and the value of PW (solid line); panels (C), (E), and (F) report the elbow angle.

Fig. 4 shows the performance of the adaptive filter in the 3 experimental conditions. In the upper panels, the EMG signals measured during 20 consecutive stimulation periods are depicted (the stimulation artifacts were removed), while the lower panels report the volitional EMG extracted by the filter. It can be noticed that the filter was able to detect an increase of the volitional EMG as the weight held by the subject increased.

Fig. 5 shows the performance of the EMG-controller in the two modalities. Panels (A) and (B) show the input and the output of the controller, while panels (C) and (D) show the elbow angle. Comparing the two modalities, it is visible that if the subject is not maintaining the contraction throughout the movement (panels (B) and (D)) the controller switched the stimulation off and the subject is not able to reach the mouth and he goes back to rest for gravity.

Discussion

The present work deals with the development of a novel EMG-based NMES controller integrated with a passive exoskeleton for upper limb support.

The preliminary results showed that the filter for the detection of the volitional EMG resulted to be very selective: it was able to extract the really low voluntary effort required for the elbow flexion when the arm weight was counterbalanced by the ArneoSpring. Moreover, the filter discriminated between increasing volitional muscle activities. First results showed that the NMES controller operation really supported the subject's intention. Next steps will be to validate the controller on severely impaired people, investigating the minimal detectable level of volitional EMG. The EMG-control system might easily be extended to other muscles in order to support more complex functional tasks.

To conclude, the present study provides a first evidence about the feasibility of an EMG-based NMES controller for daily upper limb support and represents a first step towards the design of the final MUNDUS platform.

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