A hybrid assistive system to support daily upper limb activities

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Abstract

Hybrid assistive systems (HAS) are increasingly used to improve the independence of persons with disability during activities of daily life. The HAS combined the use of functional electrical stimulation with an externally powered and controlled brace. In this work we developed a HAS to support the upper limb of people affected by severe neurodegenerative disease or high level SCI during upper limb interactions with objects of daily life. The HAS exploits any residual motor capability of the user to directly control the system itself. The novelty of the developed system lays its modularity and capability to adapt to the user's condition during disease progression. The HAS included a 3 degrees of freedom exoskeleton equipped with encoder sensors and controllable brakes, a two-channels EMG integration-based controller applied to the biceps and medal deltoid muscle, and a module able to detect in real time the user intention in order to control the system during the movement. Preliminary trials on healthy subjects were performed with a twofold objective: to select the muscles applicable to detect reliably the user's intention during daily life activities of the upper limb and to test the functionality of the system during daily life upper-limb movements. The system functionality was demonstrated and the prototype is ready to be deployed to the clinical partner to start the first tests on patients.

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

Introduction

The combination of functional electrical stimulation (FES) and an externally powered and controlled brace has become a promising technique able to blend together technologies, actuation and rehabilitation principles that could overcome the performances of each single approach [1]. This combined system is called Hybrid assistive System (HAS) [2]. Among HAS the semi-active hybrid exoskeletons are passive exoskeleton having controllable brakes at the joints able to avoid the fatiguing and unnecessary use of FES to maintain a predefined posture [1].

Robotic assistive devices have been increasingly used not only in rehabilitation but also to improve the independence and the quality of life of persons with disabilities [3]. However, most of the assistive technologies solutions for people with severe motor impairments hardly surrogate the natural human interaction with objects of daily life [3].

An innovative solution in the field may be offered by customizable and modular system able to exploit any residual motor capability of the user and empower him/her allowing natural motion of the arm in the space and natural grasping interaction with objects of daily life. This is the aim of the ongoing European project MUNDUS (MUltimodal Neuroprosthesis for Daily Upper limb Support). The MUNDUS innovation lays mainly in the modularity of its sensors, controllers, and actuators solutions that can be adapted to user's residual ability when the pathology progresses. Indeed, the expected MUNDUS users are people affected by neurodegenerative and genetic neuromuscular diseases, and high level Spinal Cord Injuries. In severe neurodegenerative impairments, the possibility to manage the same assistive technology device from the early phase of the disease to the latest one is a key issue to increase acceptability of the system itself and to enhance its usability.

The present work describes the development of a semi-active lightweight exoskeleton tailored to each single user integrated with an EMG-based neuroprosthesis to support arm reaching. The potential users of such a system are people having a residual weak control of the arm not enough to perform daily upper limb activities but able to drive the system. The device eventually could be combined with different solutions to support the grasping of cylindrical objects, if the user does not have residual hand functions.

Methods

Apparatus

Figure 1 shows a schematic representation of the developed prototype. The system includes the following components: a central controller that assures the high level communication between all the modules; an intention detection module that, according to the user's residual capability, can be based on EMG signals or on a simple USB controlled button; an arm module that comprises the lightweight exoskeleton and the EMG-based NMES controller of the upper arm muscles.

The system supports the user in reaching different objects freely placed on a table in front of him, bringing them to the mouth or to other body parts and back to the table. However, the permitted actions are not fully pre-defined since they strongly depend on the residual capabilities of each user.
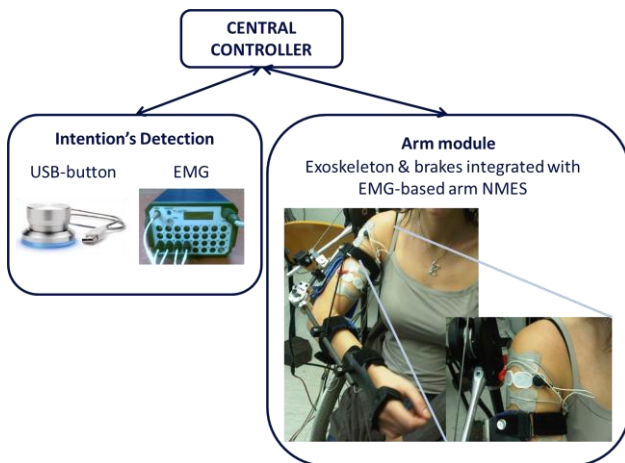

Fig. 1: Schematic of the prototype.

Central Controller

The overall control of the modules is set by the Central Controller, a state machine controller that communicates with all the modules through XML broadcast messages in order to trigger the transitions between the different states of the workflow of the supported interaction tasks. The Central Controller displays on a screen placed in front of the user some messages and questions that facilitate his/her interaction with the system. The Central Controller activates also a PC running Scilab/Scicos under real-time Linux (RTAI) used to acquire the data and control in real time the required modules.

Detection of the user's intention

The system is fully controlled by the user who interacts with the Central Controller to trigger the different sub-actions of the supported tasks. The user decides when he needs to activate and deactivate the exoskeleton joints brakes. Trigger of hand opening and closing can be included if a hand module is included. Different solutions have been implemented for the detection of the user's intention and will be selected according to the residual capability. With the less impaired subjects, the use of a simple USB-button controlled by the other hand is foreseen.

If the user is not able to control a button, the EMG activation of a single muscle is acquired. Preliminary investigations have been carried out on healthy subjects to understand which muscles are applicable to detect reliably the user's intention during daily life activities. The subjects were instructed to contract three times a single muscle within a period of 8 s (each activation should last about 1 s). When the defined pattern was detected on the EMG signal, a trigger was sent by the Central Controller to execute the action required by the user. The same pattern might trigger different actions (activation/deactivation of the brakes; opening/closing of the hand) according to the question displayed on the screen in front of the subject. The following muscles have been investigated: sternocleidomastoid muscle, frontalis muscle, orbicularis oculi muscle, neck extensors and the trapezius of the side not involved in the task execution. Artifacts on the muscle activity due to extraneous influences, such as talking, swallowing, yawning, deep breathing, smiling or sneezing have been evaluated.

Arm module

The arm module comprises a lightweight exoskeleton whose details are reported in [4]. The exoskeleton is equipped with encoders (miCAN-Stick, miControl® GmbH, Germany) to measure the angles at three degrees of freedom: the shoulder rotation in the horizontal plane, the shoulder elevation and the elbow flexion/extension (the humeral rotation is blocked by the exoskeleton). Three PC-controlled brakes are used to fix the three joints in all the possible positions achieved by the user.

An 8-channel current controlled stimulator (Rehastim™, Hasomed GmbH) is adopted to support the movement. A maximum of two muscles are stimulated simultaneously according to the user's needs. The stimulation frequency is fixed at 25 Hz; the current is set individually on each muscle, while the pulse width is controlled by an EMG-based integral. The EMG signal is acquired at 1 kHz using a commercial polygraph (Porti™, TMSI, Nederlands). The EMG electrodes are placed within the stimulation electrodes as

shown in Figure 1. An appropriate filter to detect the volitional EMG that controls the pulse width has been implemented. Details on the filter and on the EMG-based controller can be found in [5].

Results

The tests performed on healthy subjects in order to detect correctly and reliably the intention of the user from the EMG signals showed that the best muscles to be acquired were the frontalis muscle, the neck extensors and the trapezius of the side not involved in the reaching movement. The orbicularis oculi muscle was avoided because electrode placement is very uncomfortable and sometimes can be confounded with eye blinking. The sternocleidomastoid was instead highly affected during speaking, swallowing and yawning.
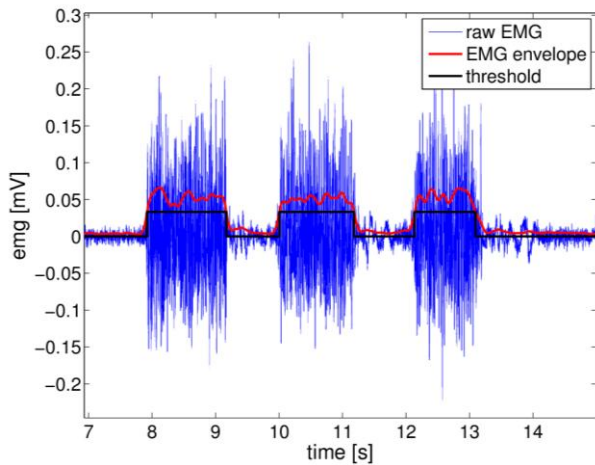

Fig. 2: The EMG signal acquired from the frontal muscle during three successive contractions.

Figure 2 shows an example of the EMG activation of the frontalis muscle according to the defined pattern. The subject contracted the muscle three times within a total period of 5 s. Each contraction lasted about 1 s. To detect the muscle activation, a standard analysis (high-pass filter with a cut-off frequency of 10 Hz, rectification, and low-pass filter with a cut-off frequency of 5 Hz) was performed on line. The muscle was considered active when the EMG envelope was over a threshold identified in a fast calibration procedure (the threshold was equal to the 25% of the maximal activation).

An example of the results obtained by a healthy subject while performing the drinking interaction task supported by the 2-channel EMG-based neuroprosthesis is shown in Figure 3. During the trial, the biceps and the medial deltoid were stimulated. The figure shows the phase during which the subject, once grasped the object on the table, reached the mouth, drank and came back to

the table. Between 57 s and 68 s, the subject was reaching the mouth and she activated both the biceps and the medial deltoids, as it can be noticed in panels (b) and (c), respectively. Therefore, stimulation was provided to both muscles to support the movement. Once the subject reached the desired position, she activated the brakes by pushing an USB-button in order to maintain the arm posture at the mouth avoiding a prolonged and fatiguing NMES use. When the brakes were switched on the subject relaxed the muscles and the stimulation was switched off. After few seconds, the subject switched off the brakes and came back to the table exploiting only her volitional activity.
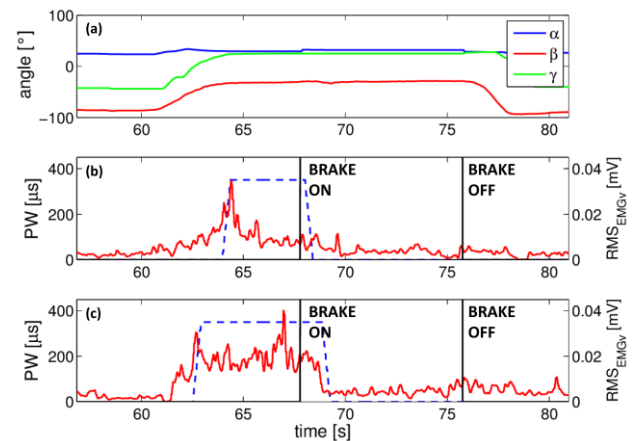

Figure 3: An example of the results obtained by a healthy user using the 2-channel integral controller. The exoskeleton joint angles (α=shoulder rotation, β = shoulder elevation and γ = elbow angle) are reported in panel (a), and the correspondence between the PW and the RMSE of the volitional EMG is reported in panels (b) and (c). Vertical lines represent the instant in which the user triggered the brake activation and deactivation.

Discussion

The work deals with the development of an innovative hybrid assistive system to support daily upper limb activities of severely impaired people. The system consists of a passive lightweight exoskeleton integrated with an EMG-based neuroprosthesis to support reaching movements. When the subject does not have any residual hand functions, different solutions to support the gross grasping of cylindrical objects are also available. In particular, two alternative solutions have been developed: an actuated robotic hand orthosis and a NMES-based grasping system including a garment with embroided stimulation electrodes. The best solution can be selected according to the user.

The main novel aspects of the developed system are the modularity and the possibility for the user

to fully drive the assistive device. According to the user's residual capability, different configurations of the system (only the passive exoskeleton, the exoskeleton integrated with the neuroprosthesis, the hand module, etc.) is automatically created and the Central Controller adapts its workflow to the proper configuration. The system software provides also an interface which helps the caregiver to setup the system for the user (donning and calibration of all the required modules).

The whole MUNDUS project aims at developing a platform that can follow the users in the degeneration of their pathology so to keep them as longer as possible capable to interact with their own arm in a workspace where different functions could be available.

Up to know, the functionality of the system has been evaluated only on healthy subjects. The reliability, the effectiveness and the usability of the system by the real end-users will be evaluated soon. A group of potential users has been identified and they will be trained to use MUNDUS during daily upper limb activities.

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