FES controlled by a hybrid BCI system for neurorehabilitation – driven after stroke

P. Aricò, F. Aloise, F. Pichiorri, F. Leotta, S. Salinari, D. Mattia and F. Cincotti

1 Neuroelectrical Imaging and BCI Lab, Fondazione Santa Lucia IRCCS, Rome, Italy
2 DIAG, Sapienza University of Rome, Italy
3 Department of Neurology and Psychiatry, Sapienza University of Rome, Italy

Abstract—The objective of this work is to provide a Brain Computer Interface (BCI) – driven rehabilitative device, which incorporates Functional Electrical Stimulation (FES), for the rehabilitation of the upper limb in stroke patients. The proposed system is designed in agreement with the neurorehabilitation experts and is meant to comply with the current rehabilitation principles. The main innovative characteristic of the device would be the “hybrid” control of the FES system, meant to reinforce both motor intent (as recorded by EEG) and the associated residual motor ability (electromyography, EMG). Furthermore, FES would provide for an enriched sensorimotor feedback with the aim of boosting motor scheme re-learning by allowing voluntary access to the stroke affected hand.

Keywords—BCI, EEG, EMG, FES, Stroke, Rehabilitation.

I. INTRODUCTION

In BCI applications for stroke rehabilitation, sensorimotor (SMR) BCI systems are used with the aim of providing patients with an instrument that is capable of monitoring and reinforcing EEG patterns generated by motor imagery (MI). This task-specific training is meant to improve motor recovery by exploiting the activity-dependent brain plasticity phenomena [1]. A further implementation of rehabilitative protocols can be achieved by employing motor-related brain activity to supplement impaired muscular control [2]. In the rehabilitative path of a stroke patient the practice of MI is meant to improve actual motor recovery; therefore, therapists encourage and reinforce any residual (or recovered) execution of the MI trained hand movements, yet ensuring that this does not induce unwanted contractions and spasticity.

The aim of the present work is to provide a BCI-driven rehabilitative device to boost motor recovery of the upper limb in stroke patients. The prototype system would use electroencephalography (EEG) and electromyography (EMG) signals generated from the motor attempt in order to control a FES device designed to complete and reinforce the attempted movement. EEG signals will be monitored and will function as a gating for the EEG-based control of the FES system. In this hybrid approach, the motor intent of a given patient is recognized (EEG patterns) and the muscle contraction is produced via FES only if a specific EMG features of the patient’s voluntary motor attempt are authenticated as “correct” (EMG signal functions as a “gate” for the BCI control of FES device). The training will take place in a proper rehabilitative setting with the presence of the therapist, and both the EEG and the EMG feedback will be under the therapist’s supervision. In the proposed BCI system we will ask the patient to attempt simple hand movements (grasping, finger extension) and introduce the FES device in order to provide a feedback to the patient.

II. MATERIAL AND METHODS

A. System implementation

The communication between system modules was realized using Tobi interfaces. Particularly Tobi interface A (TiA) is a standardized interface to transmit raw biosignals (e.g. EEG and EMG raw signals), Tobi interface C (TiC) allows to exchange in a standardized way messages between modules (e.g. output of EEG, EMG and Fusion classifiers) and Tobi interface D (TiD) allows to exchange in a standardized way high-level events between modules (e.g. time line of the experiment, start/stop events) [3]. Figure 1 shows an overview of the software and hardware hybrid system.

Figure 1. Hardware and Software prototype components

Acquisition (32 EEG and 4 bipolar EMG channels, gTec technology, Graz Austria) is driven by the TOBI Signal Server (an application running in background, capable of driving one or more biosignals amplifiers), which relays acquired data to the two following processing blocks (BCI2000 SMR Signal Processing/Matlab® EMG Signal Processing) in data streams compliant to the TOBI Interface A (TiA) definition. The SMR classifier is a modified version of the BCI2000 framework [4], configured to run a MI-based classification acquiring data directly from the Signal Server through a TiA connection. Classification results are transmitted to the Fusion application in TOBI Interface C (TiC) format. The EMG classifier, the Fusion and the Controller modules are implemented in Matlab®, and feature similar connections as the SMR classifier (TiA from the Signal Server, TiC to the Fusion Module). The Fusion Module receives classification outputs from both the SMR and the EMG classifiers, and transforms them into “fusion classes”. These classes are transmitted to the Controller.

...
Module, that manage both the Visual Feedback Module and FES Controller. Auxiliary data (integrated SMR amplitude and instantaneous EMG activity) are stored in the TiC messages, and are used to feed the Therapist Feedback (Figure 2). Also the Controller Module provides the clock to the whole system (TiD messages), in accordance to the parameters previously set by the operator. FES is controlled via the exchange of information through a serial communication. A specific software program was developed to translate the high level events issued by the Controller Module (i.e. “start FES feedback”) into a sequence of low level commands which specify the desired behavior of the stimulation device. The FES controller is configured to establish a network connection with the Controller Module, from which it receives messages in TiC format. Upon reception of an activation message, a sequence of stimulation is performed on either extensor or flexor muscles. While the patient only receives feedback at the end of a successful trial (i.e., activation of FES), the therapist must receive more information while monitoring the training session. The therapist feedback is controlled by means of the same Matlab® software module in which fusion of EEG + EMG classifier occurs; that is, information on the internal state of the classifiers is forwarded in the same structure containing the final results of classification (TiC format). Figure 2 illustrates the panels available on the therapist’s screen.

B. EMG classification

For EMG classification, extraction of the Linear Envelope is used to obtain a signal that is directly correlated with the strength of contraction. The processing steps for its computation are the follow:

Frequency filtering. Low frequency components, mostly due to motion artifacts, and 50 Hz contamination is removed with a high pass and a notch filter, respectively. High pass filter (low cut-off 20 Hz) ensures that the signal is symmetric with respect to the baseline.

Rectification. The absolute value of the EMG signal is computed. The signal has now positive value, and its sum is proportional to the EMG power.

Low-pass filtering. When the time course of muscular activation is needed, rather than integrating the rectified signal over a trial, a digital low pass filter with cut-off frequency below 10 Hz is applied. This step produces an estimation of the envelope of the signal.

Four muscles are considered (Finger flexor and Finger extensor, biceps and triceps) and two tasks (Finger extension and Grasping). Condition that must be met in order to detect a desired muscular pattern is:

Extension: 
\[
[[\text{En}(\text{Eb})+\text{Tn}(\text{Tb})]+[\text{Fn}(\text{Fb})+\text{Bn}(\text{Bb})]] \geq \text{thr}
\]

Grasping: 
\[
[[\text{Fn}(\text{Fb})+\text{Bn}(\text{Bb})]+[\text{En}(\text{Eb})+\text{Tn}(\text{Tb})]] \geq \text{thr}
\]

F = Finger Flexor Envelope
E = Finger Extensor Envelope
B = Biceps Envelope
T = Triceps Envelope
Mn = Muscle Maximum
Mb = Muscle Rest
thr = Threshold (≥ 0)

During a “calibration phase” patient is required to make the ceilings for each muscle, interspersed with rest periods. Therapist can choose the action sequence to do, and can manually start the next action. The calibration parameters of the system (Mn, Mb, thr) are automatically extracted from the EMG module. Therapist can also make manual adjustments of these parameters and manually set the threshold value (thr) which must be exceeded to satisfy the rule. The rule output is integrated during the experiment. Integration is reset to zero at the beginning of each trial. Classifier outputs a successful detection when the integrated score exceeds the threshold (thr).

Figure 2. Snapshot of the therapist feedback in the proposed hybrid-BCI prototype system: Instantaneous (A) and time courses (F) values of integrated SMR scores; Instantaneous (B) and time courses (H) values of integrated EMG pattern scores; Instantaneous (C) and time courses (G and l) values of Linear Envelope of each muscle’s EMG after the calibration phase: Mn(M-Mb); Final result of the EEG and EMG classifiers (D); Final result of the Fusion classifier (E); New Trial Button: the therapist can start a new trial (L); Reset Button: set to zero the value of the rule (M); Close Button: stop the experiment (N).

III. CONCLUSION

Preliminary tests in the laboratory with healthy volunteers have shown the feasibility of the novel implementation. The prototype system has been installed in a rehabilitation hospital ward and is currently under testing with the participation of stroke patients and rehabilitation experts.

ACKNOWLEDGEMENT

The work is partly supported by the EU grant FP7-224631 “TOBI” (Tools for Brain-Computer Interaction). This paper only reflects the authors’ views and funding agencies are not liable for any use that may be made of the information contained herein.

REFERENCES


