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Controlling a FES-EXOSKELETON Rehabilitation System by Means of Brain-Computer Interface

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***Abstract*—This paper presents the analysis and the implementation of a robotic rehabilitation device which couples a Brain-Computer Interface (BCI) and a robotic FES (Functional Electrical Stimulation)-exoskeleton system for upper limb rehabilitation of persons with neuromotor disabilities. This system combines two types of therapies used in neurorehabilitation: one using functional electrical stimulation and one using movements driven by an electrically powered exoskeleton. FES can coordinate the activation of certain muscle groups having as result movements which are similar to the normal ones. The main goal of this system is to allow people with disabilities to reach and maintain an optimal physical function. The FES-exoskeleton device is controlled by a BCI system. The control strategy of the entire system was implemented in MATLAB&Simulink environment. BCI technology involves monitoring the brain electrical activity and detecting special characteristics of EEG (electroencephalogram) using advanced signal processing algorithms. The BCI principle used for controlling the developed system is the Motor Imagery (MI). By imagining the left or right arm movement, the user can control the FES-exoskeleton system to perform forearm flexion and extension and hand opening.**

Keywords*—Exoskeleton, Brain-Computer Interface, Functional Electrical Stimulation, neurorehabilitation, wearable exoskeleton

I. INTRODUCTION

European health sector is an area where technology innovation plays a major role in supporting socio-economic cohesion and regional policy. The role played by the rehabilitation devices in any health system is very important because they introduce innovation, edge technologies and also significantly contribute to enhance the quality and efficiency of health systems. The whole rehabilitation strategy successfully folds on the European strategy 'Health 2020' - healthy aging of population and falls also on the third European health perspective that relates to the development of competitive innovative technologies which are revolutionizing the way to prevent and treat diseases [1], given that Romania is in the world's top ten in terms of stroke incidence.

According to Health Ministry of Romania, morbidity and mortality data show a mixture of specific indicators in developing countries, mortality by cardio-vascular growth of neoplastic diseases, as well as the resurgence of infectious diseases. In Romania, a number of 468 635 patients are diagnosed with stroke. 212714 of them are men (45.4%) and 255921 women (54.6%). Median age is 65.23 years for men and 67 years for women [2]. Stroke mortality is three to four times higher in our country than in EU countries. The existing rehabilitation programs consist of multidisciplinary approaches that bring together neurologists, psychologists, speech therapists and physio-kineto therapists. This approach is complex and expensive due to the repetitive nature of the recovery process that induces burdensome costs. For this reason, different rehabilitation systems were created integrating Functional Electrical Stimulation (FES), rehabilitation robots or haptic interfaces that reduce the final number of people involved in the rehabilitation process. Appropriate muscle training can enhance muscular strength, power, and endurance but also improve health and fitness by reinforcing cardiopulmonary functions, reducing body fat, improving the mineral density of the bone, and providing other benefits [3].

In general, electrical stimulation may be used therapeutically or functionally. The benefits of the therapeutic electrical stimulation can be:

- Improving muscle tone and preventing the atrophy of the paralyzed muscles;
- Reducing spasticity;
- Improving blood circulation and skin health [4].

Many rehabilitation systems were designed to substitute some functions of the upper limbs in disabled people. These systems are based either on functional electrical stimulation, on rehabilitation robots or on haptic interfaces.

In this paper we present the analysis and implementation of a control system using a Brain-Computer Interface (BCI) and a hybrid FES-exoskeleton system specially designed for upper limb rehabilitation in post-stroke patients. This system combines two kinds of therapies: one using FES and the other one using movements driven by an electrically powered exoskeleton. FES can coordinate the activation of certain muscle groups, having as result movements which are similar to the normal ones. The primary purpose of this device is to allow people with disabilities to reach and maintain a better

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physical function and to give them back the voluntary control over the affected upper limb.

The FES-exoskeleton device is controlled by a brain-computer interface. The control strategy of the entire system was implemented in MATLAB&Simulink environment. BCI technology involves monitoring brain electrical activity and detecting its main characteristics using advanced signal processing algorithms. The BCI principle used for controlling the developed system is Motor Imagery (MI). By imagining the left or right arm movement, the user can control the FES-exoskeleton system to perform the forearm flexion and extension and hand opening.

II. System Description

The FES-exoskeleton system opens a new path on recovering the upper limb functionalities which were partially or totally lost after a stroke incident, multiple sclerosis (MS), spinal cord injuries (SCI), etc. The robot is modular and adaptable, allowing therapists to quickly adjust to new situations and thus suitable for long-term use in daily activities. The exoskeleton has been designed with anthropometric dimensions and it has 3 degrees of freedom. The developed system integrates a non-invasive brain computer interface (BCI) based on motor imagery. BCI can distinguish whether the user is imagining the movement of the left or right arm. Based on this work it was developed a control strategy for the FES-exoskeleton system for flexion and extension of the forearm together with stimulation of muscles in order to reach and grasp an object. Thus, users can learn to use the exoskeleton system for basic daily activities. The proposed rehabilitation system consists in mechanical exoskeleton structure dimensioned anthropometric so as to ensure anatomical basic movements together with functional electrical stimulation.

The novelty consists in the combined control of movements which are induced by the electrical stimulation and correctly driven by the exoskeleton. The proposed device has a modular and reconfigurable structure and generates electrical stimulus in order to induce muscle contraction and therefore creating the premises to regain the upper limb functional movements. The electrical stimulus are generated by a programmable 8 channels neurostimulator MOTIONSTIM8 (MEDEL GmbH, Medicine Electronics, Hamburg, Germany). Based on the control strategy, two Sabertooth® controllers are capable to operate the exoskeleton motors. The main movements that can be achieved are shoulder flexion-extension, shoulder abduction-adduction, shoulder medial rotation and forearm flexion extension. To obtain information on the position of each joint of the exoskeleton, potentiometers were installed on each shaft of the geared DC motors. The analog signals generated by the potentiometers are read and processed by a Basic Atom 28Pro microcontroller.

The schematic diagram of the operation of BCI-FES-exoskeleton system is shown in Fig. 1. The control strategy provides online visual feedback (a left or right arrow on the monitor) and at the same time induces movements by means of functional electrical stimulation, movements which are also driven by the exoskeleton. The discrimination between two classes of motor imagery was done using the common spatial patterns (CSP) method [5].

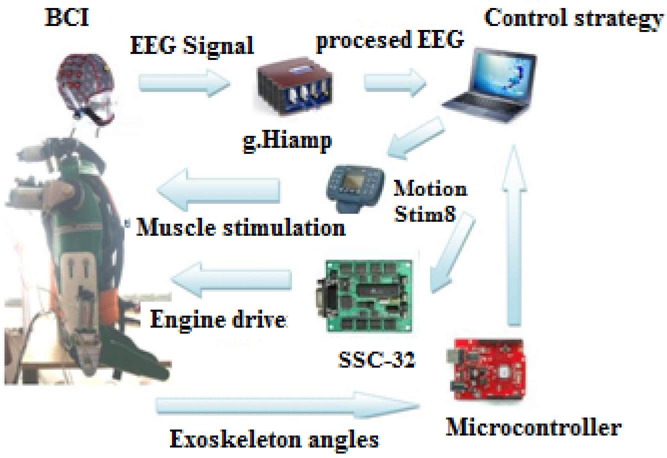

Fig. 1. Schematic diagram of the BCI-FES-exoskeleton system.

During a working session with the presented system, the subject has to imagine the movement of an arm. The BCI interface records and processes the EEG signals and sends them to the computer. The implemented CSP method, together with a Linear Discriminant Classifier (LDA) determines which hand was imaginary moved. Based on this result, the control strategy controls the MotionStim8 neurostimulator and at the same time the DC motors of the exoskeleton in order to obtain an arm movement.

III. Experimental Setup and Results

The system was tested on a healthy person. The Simulink online model for controlling the whole system is presented in Fig. 2. The EEG data was collected using 16 active electrodes (g.LADYbird, g.tec medical engineering GmbH) overlying the sensorimotor areas as presented in Fig. 3, amplified with a g.HIamp biosignal amplifier, filtered between 0.5 to 30 Hz with a 8th order Butterworth bandpass filter and then passed to the PC where the digital data processing was done. The Simulink online model contains the amplifier block which feeds the CSP filter block with the hardware filtered signal. The output of the CSP block is bandpass-filtered between 8 to 30 Hz and then the variance is calculated for a 1.5 seconds time window. The variance blocks output signals are normalized and fed to the apply classifier block which drives the visual paradigm block. The visual online feedback, FES and exoskeleton movements were controlled by the implemented control strategy (EXOSLIM block) based on the LDA classification result and the exoskeleton joints angles. To obtain flexion-extension motion and extension of the hand, the electrodes were placed on the biceps, triceps and wrist extensors muscles.

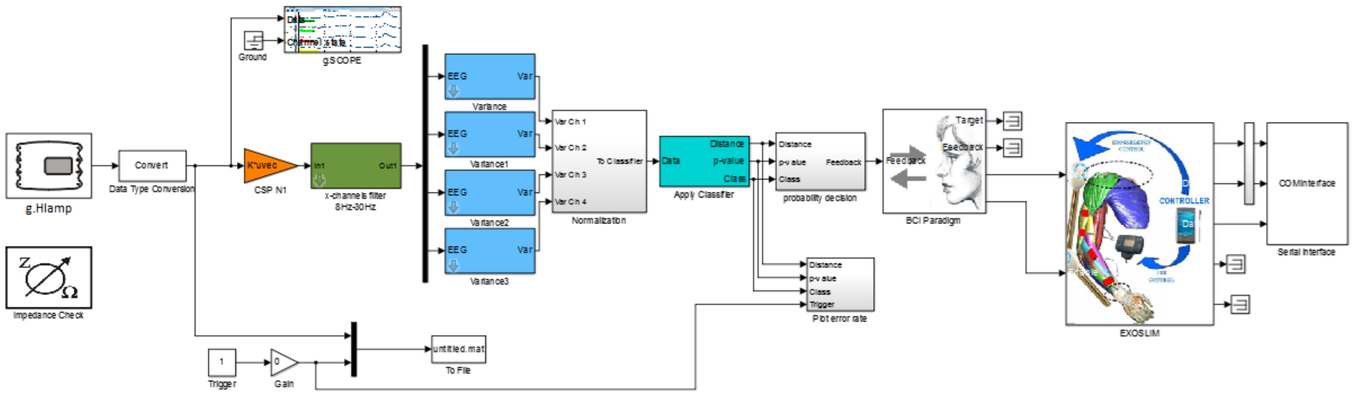

Fig. 2. The Simulink online model for controlling the BCI-FES-exoskeleton system.

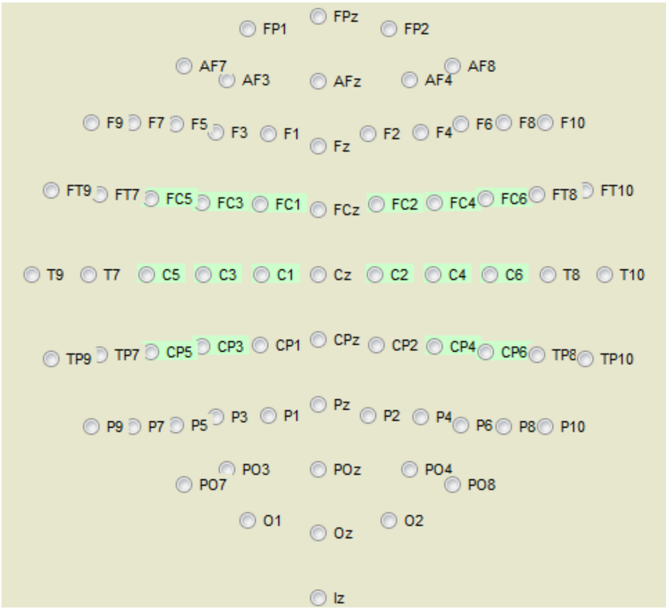

Fig. 3. Electrodes displacement based on the 10-20 International System.

After the calibration procedure of the MI-based BCI system, where the CSP filters and LDA classifier were created according to Ortner et al.[6], starting with the emergence of the cue, a red arrow pointing to the right or the left side of the monitor, the user had to imagine the movement of the corresponding upper limb. If the classified movement was the left arm, the exoskeleton performed an elbow flexion along with the stimulation of biceps and hand extensors (fig. 4). If the elbow was flexed and the next classified movement was right, the exoskeleton returned to the original position along with triceps muscle stimulation (fig.5). The first channel of the neurostimulator was used for the biceps muscle stimulation, the second one for the hand extensors and the third one for the triceps muscles. The FES-induced movements were performed in a slowly and controlled manner. It was shown that the physical force can be enhanced in a manner dependent on the duration and frequency of the exercise, without increasing spasticity [7, 8].

Fig. 6 presents the spatial patterns of our subject. These are topographic maps, where the electrodes are marked with white dots. The top two plots show the activity during imagination of right hand, and reflect an activation of regions around site C3, which is marked with a white circle. The bottom two plots show the cortical activity during the imagination of left hand movement, showing the activation around the site C4. During the experiment, the subject managed to control very well the BCI system.

Fig. 4. BCI-FES-Exoskeleton system while performing elbow flexion.

Fig. 5. BCI-FES-Exoskeleton system while performing elbow extension.

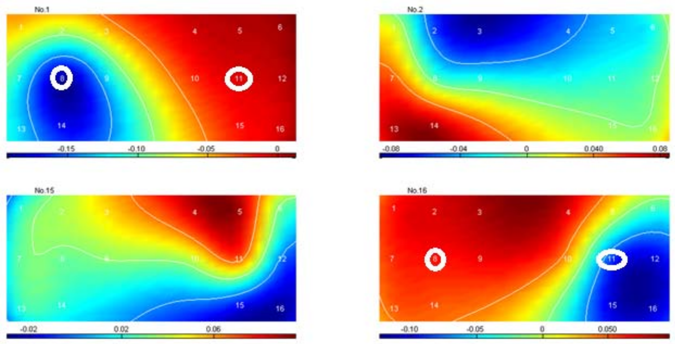

Fig. 6. Example of the CSP patterns of our healthy subject.

After the experiment, the user reported that the he felt confortable while wearing the exoskeleton, and while performing movements he felt no pain due to FES or due to the mechanical arm.

IV. Conclusions

This paper presents a complex control system designed for the upper limb rehabilitation that differs from existing devices by using BCI and combined control exercises with balance between functional electrical stimulation and exoskeleton driven movements. The proposed rehabilitation system consists of an anthropometric sized exoskeleton which can assist a patient while performing basic anatomical movements (flexion-extension shoulder, shoulder abduction-adduction, medial rotation of the shoulder and forearm flexion-extension) together with FES. It has a modular, reconfigurable and adaptable structure and can be mounted on a patient by a single therapist in about 5 minutes. Developing a software interface between BCI and rehabilitation FES-exoskeleton system represents a breakthrough in the post-stroke rehabilitation field because the patients can coordinate the movements of the upper limb through movement imagination. The discrimination between the two classes of motor imagery was carried out with the Common Spatial Patterns method which is well known for this kind of tasks. The movements obtained during this experiment were forearm flexion and extension and opening of the hand, and they were triggered by the healthy subject through the BCI.

In the scientific literature there are studies where the MI-based BCIs were used as rehabilitation tools, for example Ang et al. [10], Ortner et al. [6,11], Remsik et al. [12] and others. Hence, our system could combine the advantages of the techniques it combines (BCI, FES and robotic assisted movements) and become a good tool for the rehabilitation process of the stroke patients. Moreover, this kind of exercises could make the patient to be more involved in the rehabilitation process, fact that could add additional benefits to the rehabilitation process results. At the same time, the proposed system combines the FES effects on the neuroplasticity with the capability to replicate precisely voluntary movements driven by the exoskeleton.

Acknowledgment

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References

[1] World Health Organization, "HEALTH 2020 - A European policy framework supporting action across government and society for health and well-being", ISBN : 978 92 890 0278, 2014

[2] Neagoe, Mariana-Alis; Armean, Petru; Lupan, Cristina „Tendița factorilor de risc conventionali la pacienții spitalizați cu AVC în perioada 2008-2010". Revista Medicală Română. Volume LIX, nr1., 2012.

[3] C.J. Hass, M.S. Feigenbaum, B.A. Franklin, Prescription of resistance training for healthy populations, Sports Med. 31 (14) 953–964, 2001.

[4] Poboroniuc M. Elemente de programare și control a neuroprotezelor, Editura Venus, ISBN 978-973 -756- 036 -0, 2006.

[5] Guger C., Ramoser H., Pfurtscheller G., Real-time EEG analysis with subject-specific spatial patterns for a Brain-Computer Interface (BCI), IEEE Trans Rehabil Eng 8(4), pp. 447-456, 2000.

[6] Ortner R., Irimia D.C., Scharinger J., Guger C., "A Motor Imagery based Brain-Computer Interface for Stroke Rehabilitation", Studies in health technology and informatics 181:319-23, September 2012, DOI: 10.3233/978-1-61499-121-2-319.s

[7] Tzong-Ming Wu, Shu-Yi Wang, Dar-Zen Chen, Design of an exoskeleton for strengthning the upper limb muscle for overextension injury prevention, Mechanism and Machine Theory 46, pp.1825–1839, 2011.

[8] Van der Lee JH, Snels IA, Beckerman H, Lankhorst GJ, Wagenaar RC, Bouter LM: Exercise therapy for arm function in stroke patients: a systematic review of randomized controlled trials. Clin Rehabil; 15:20-31, 2001.

[9] Pomeroy VM, King LM, Pollock , Baily-Hallam A, Langhorne P: Electrostimulation for Promoting Recovery of Movement or Functional Ability After Stroke. Systematic Review and Meta-Analysis. Stroke; 37:2441-2442, 2006.

[10] Ang K. K., Guan C., Chua K. S. G., Ang B. T., Kuah C. W. K., Wang C., Phua K. S., Chin Z. Y., and Zhang H., "A large clinical study on the ability of stroke patients to use an EEG-based motor imagery brain-computer interface," Clinical EEG and Neuroscience, vol. 42, no. 4, pp. 253–258, 2011.

[11] Ortner R., Irimia D.C., Guger C., Edlinger G., "Human Computer Confluence in BCI for Stroke Rehabilitaion", Foundations of Augumented Cognition, Chapter: Human Computer Confluence in BCI for Stroke Rehabilitation, Publisher: Springer International Publishing, Editors: Dylan D. Schmorrow, Cali M. Fidopiastis, pp.304-312.

[12] Remsik, A, Young, B, Vermilyea, R, Kiekhoefer, L, Abrams, J, Evander Elmore, S, Schultz, P, Nair, V, Edwards, D, Williams, J, Prabhakaran, V. A review of the progression and future implications of brain-computer interface therapies for restoration of distal upper extremity motor function after stroke.Expert Rev Med Devices. 2016 May;13(5):445-54.