Post-Stroke Hand Rehabilitation Using a Hybrid FES-Robotic Glove

Danut C. Irimia, Marian S. Poboroniuc, Sergiu Hartopanu, Daniel Sticea, Georgel Paicu
Faculty of Electrical Engineering
"Gheorghe Asachi" Technical University of Iasi
Iasi, Romania
danut.irimia@tuiasi.ro, mpobor@tuiasi.ro

Bogdan E. Ignat
Department of Neurology
"Grigore T. Popa" University of Medicine and Pharmacy
Iasi, Romania
bogdanei@yahoo.com

***Abstract*—This paper presents the preliminary results of testing a hybrid FES-Robotic Glove specially designed for the rehabilitation process of the upper limb in stroke patients. This system brings as novelty the balanced control between the functional electrical stimulation used for artificially inducing the hand extensors contraction and the robotic glove which coordinates the fingers to perform proper movements. The system has been tested on a healthy person in laboratory and on a stroke patient within clinical environment.**

***Keywords*—Neuroprostheses, Functional Electrical Stimulation, Robotic Glove, Neurorehabilitation.**

I. Introduction

Nowadays, stroke represents the main cause of motor disabilities in adults and the second leading cause of death worldwide. The World Health Organization stated in an article that in 2012 around 6.7 million people suffered a stroke [1]. In the last decade researchers in motor rehabilitation field aim to facilitate the neuroplasticity by means of neurofeedback, by using assistive robotics in task specific training and by using functional electrical stimulation (FES) for inducing different kind of movements.

In the last few years, the interest of using the robotic devices in neurorehabilitation has grown significantly. It has been found that robot-assisted upper limb training is safe and can improve effectively the paretic arm functions and activities of daily living in patients who had a stroke [2,3,4,5]. Varalta et al. [6] have investigated the effects of hemi-spatial neglect of a training program based on contra-lesional robotic limb activation in three stroke patients. They used the Gloreha® (Idrogenet srl, Lumezzane, Italy) hand rehabilitation glove which provides computer-controlled, repetitive, passive mobilization of the fingers. The artificial tendons incorporated in the glove moved the fingers and the subjects hand movements were visualized as a real-time 3D animation on a computer monitor. Their results indicate that robot assisted left hand training could improve not only visuospatial exploration and attention but also speed to execute gross movement of the arm, hand and fingers, as well as fingertip dexterity.

In other study, Vanoglio et al. [7] have evaluated the feasibility and efficacy of robot-assisted hand rehabilitation in improving arm function abilities in sub-acute hemiplegic patients. They recruited 27 hemiplegic stroke patients and randomly divided them in two groups, 14 in the Treatment (target) group and 13 in the Control group. The patients in the target group received intensive robotic-assisted hand training with the Gloreha® glove with multisensory feedback while the patients in the control group received the same time of treatment only with conventional therapies. The results were not significantly different between the two groups but proved that the robotic glove is feasible and effective in recovering the fine manual dexterity and strength and in reducing the arm disability in sub-acute hemiplegic patients.

This publication presents a novel device for robotic-assisted post-stroke rehabilitation called "Intelligent Haptic Robotic Glove - IHRG", which couples a robotic glove and the Functional Electrical Stimulation (FES) technology. The novelty of this device consists in the balanced control between the electrical stimuli for generating the muscle contraction and the robotic glove which coordinates the fingers for proper movements. On one hand, IHRG allows patients to perform with the affected hand the same movements as with the healthy hand. On the other hand, it can detect the patient's intention to move the affected hand and based on that it can trigger a hand opening and closing exercise. The system has been tested on a healthy person and on a stroke patient within clinical environment.

II. System Description

The robotic glove consists of a left-side leather glove with metal tendons attached on the dorsal side for achieving active finger flexion and extension movements (Fig. 1.a). The electrical stimulus, provided by a MOTIONSTIM8 neurostimulator, are applied on the interosseous muscles and on the hand extensors, in order to induce a proper hand opening movement (Fig. 2).

The device can assist the patient while performing two types of exercises. The first type detects the patient's intention to move the affected hand by using a bending sensor attached to the middle finger of the robotic glove and triggers a pre-defined set of movements. The other type copies the finger

978-1-5090-6129-7/16/$31.00 ©2016 European Union

movements of the healthy hand by using a second glove equipped with five bending sensors (Fig. 1.b).

a b

Fig. 1. a) – Robotic glove with metal tendons attached; b) – glove equipped with bending sensors for copying the healthy hand finger movements.

Fig. 2. FES electrodes placement for achieving the hand opening movement.

The software controlling the entire system was developed under MATLAB&Simulink environment. It allows users to set the electrical stimulation intensity, pre-define finger movements, selecting the exercise and to record the patient's performance like the number of movements of each finger, range and stimulation pulse widths and currents. Fig. 3 presents the hardware system components detailing the connections in-between them.

The robotic glove fingers are actuated by linear servomotors (Firgelli 12) which are controlled by an Arduino Uno microcontroller with pulse-width modulated signals. The signals provided by all bending sensors, from both gloves, are read and converted to digital by this microcontroller, and sent to the computer, where the main control strategy is implemented and which controls the functional electrical stimulation.

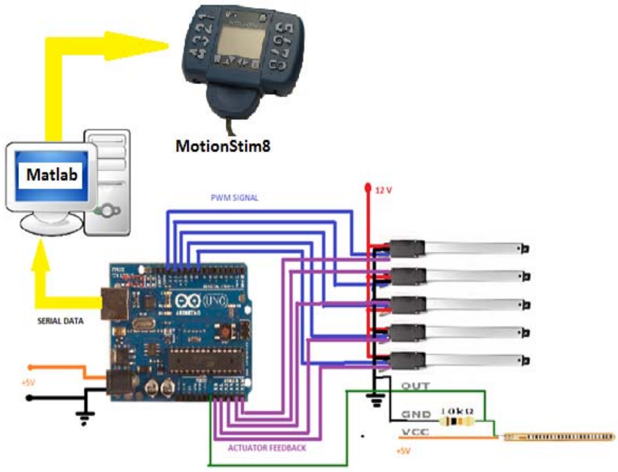

Fig. 3. Hardware components and connections of the proposed system.

For the first type of exercise, where the glove will perform flexion-extension exercises triggered by the patient intention to move the hand, the bending sensor placed on the middle finger of the robotic glove is used on one hand for detecting the patients intention to move the hand and on the other hand for detecting the fingers position while performing the pre-defined movements (flexion and extension). Fig. 4 presents the output signal of the bending sensor placed on the middle finger of the robotic glove while scanning for the patient's intention to move the hand. The bigger spikes are marked with red and numbered. The bigger one (no. 4) is the one that exceeds the threshold and triggers the pre-defined movements. The threshold (figured with magenta solid line in fig.4) is calculated as 80% of the mean of the four highest spikes detected in the calibration phase.

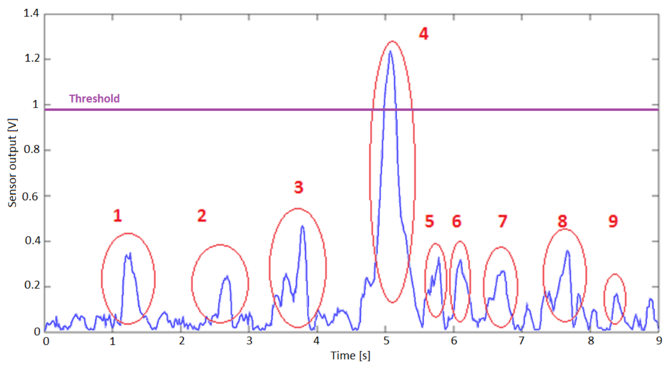

Fig. 4. Detecting the patient's intention to move the affected hand.

Fig. 5 presents the outputs of the sensors placed on the glove designed for the healthy hand while performing the second type of exercise – copying the healthy hand movements. The main problem in this case is the positioning speed of the servomotor shaft. While performing the finger flexion movement, which naturally takes 1 to 1.5 seconds, the response time of the servomotors is almost 7 seconds. However, taking into account the facts that the system will be used by stroke patients and that it is important for them to perform the movements slower, the response time of the Firgelli servomotors will not represent a problem

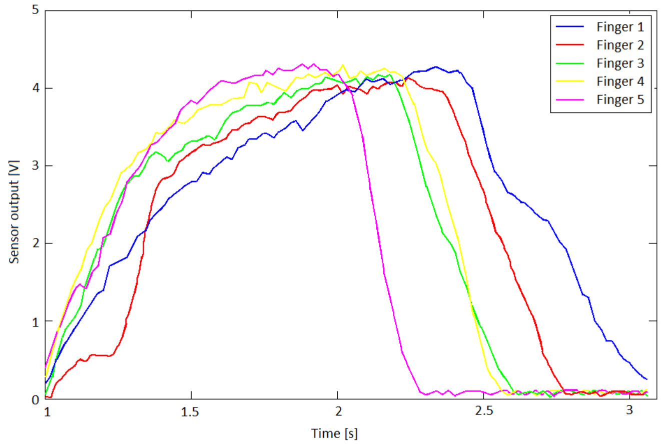

Fig. 5. Sensors output while performing fingers flexion-extension exercises with the healthy hand.

III. RESULTS

After receiving the approval from the Ethical commission, we started the tests of the system within clinical environment under the close supervision of the medics. Until now we have tested the system only on a single patient. Fig. 6 presents the FES channels pulse widths and the bending sensors feedback for a time segment 100 seconds from the healthy hand copying exercise. It can be seen the correspondence the between the variations of the values received from the bending sensors placed on the healthy hand and the sensor placed on the robotic glove. The delay given by the servomotors positioning is not present anymore because the flexion and the extension of the healthy hand were done at the same time with the affected hand movements. In the upper plot, the red and blue solid lines represent the pulse widths of the functional electrical stimulation signals on channels one and two. The green solid line represents the position of the middle finger of the robotic glove. This signal was represented in % where 100% corresponds to fingers totally flexed and 0% to fingers totally extended. The lower plot presents the signals recorded from the healthy hand, represented in percent, with the same signification as the signal from the sensor placed on the robotic glove.

The patient performed also the other type of exercise – triggering a pre-defined movement with the intention to move the affected hand. Fig. 7 presents the FES signals pulse width and the sensor feedback for a time segment of 60 seconds from this exercise. The blue and red solid lines represent the FES signal pulse widths for channels 1 and 2 while the green line represents the finger position of the robotic glove. The FES pulse width increases proportionally with the fingers extension level of the affected hand. When the hand is in total flexion position, the signal coming from the bending sensor placed on the robotic glove reaches the 100% value and when the hand is in the maximum extension position the signal goes to zero. The areas marked with red circles and numbered from one to three represent the movement intentions of the user's fingers.

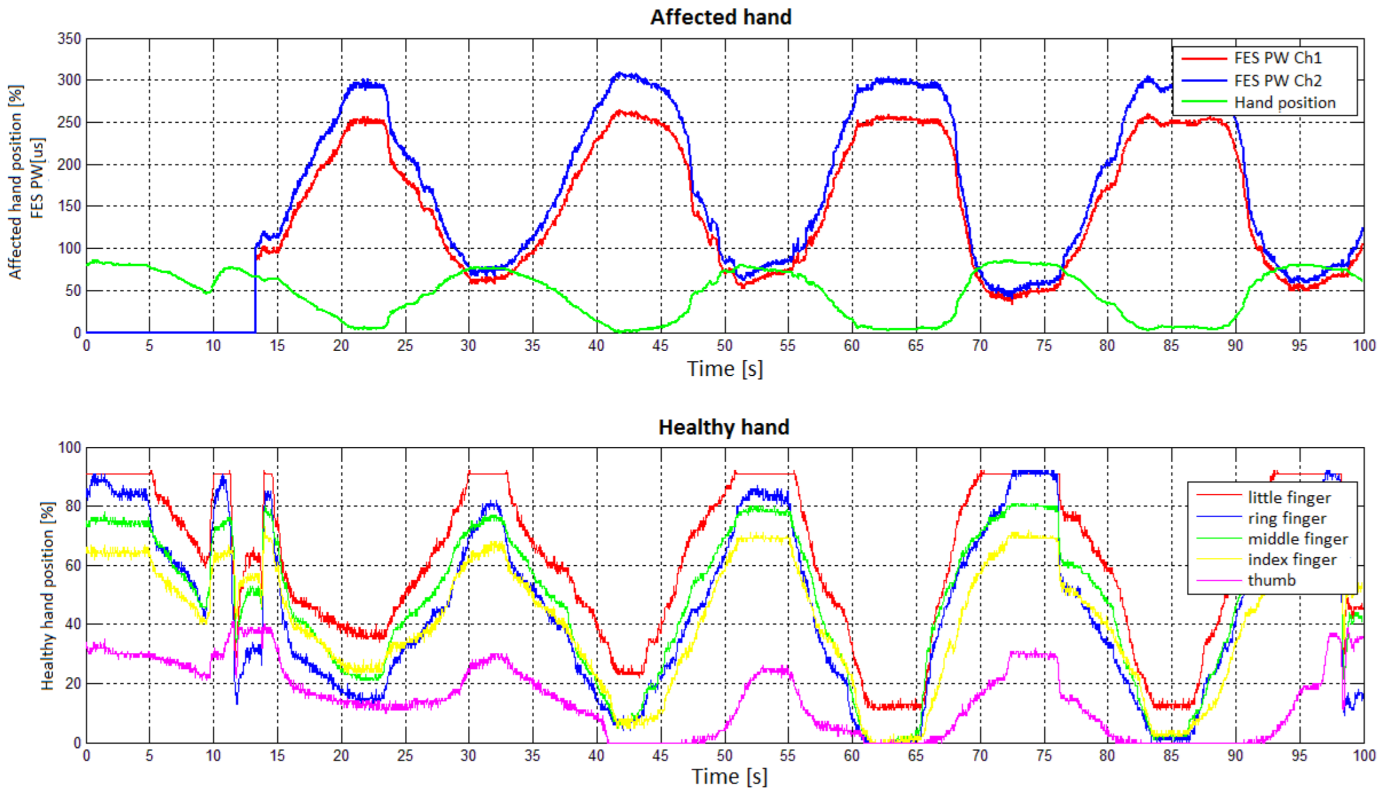

Fig. 6. FES channels pulse widths and bending sensors feedback while performing the healthy hand movement copying exercise.

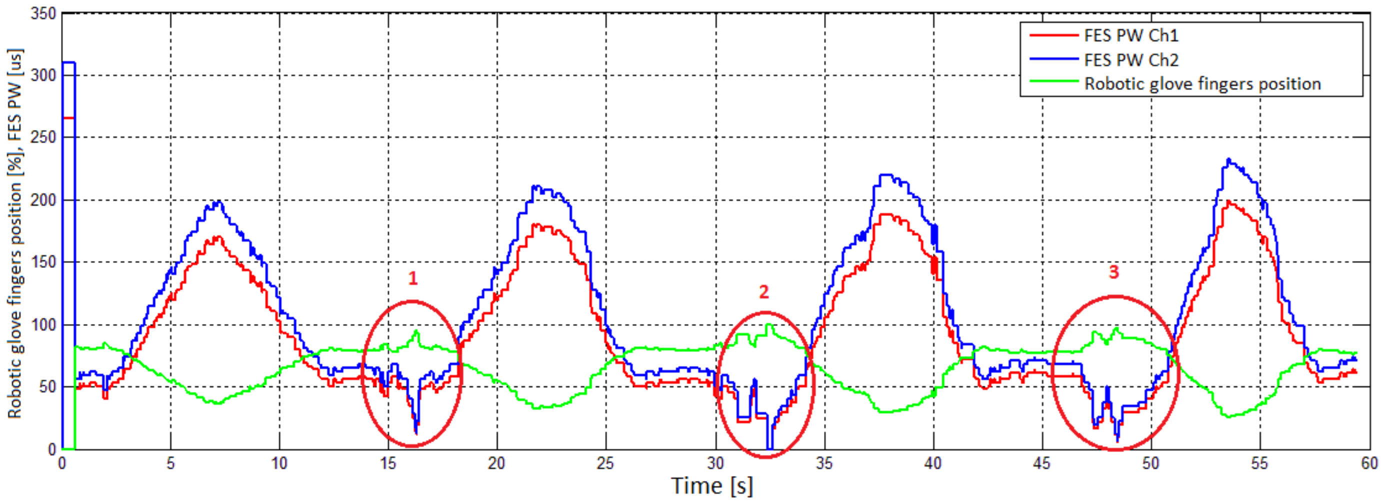

Fig. 7. FES channels pulse widths and bending sensor feedback while triggering the pre-defined exercise with the intention to move the affected hand.

After detecting the movement intention, the system performs an extension-flexion movement in 5 to 6 seconds then waits again for the user's intention to move the hand. For inducing the proper movements with FES, in the calibration phase the maximum stimulation parameters where chosen as follows: for Ch1the maximum pulse width was 256 µs with 9 mA current; for CH2 the maximum pulse width was 305 µs with 10 mA current. While inducing the movements with FES, the stimulation current was maintained constant and only the signal pulse width was modulated.

After working with the proposed system, our first patient was very happy with the experience mostly because the dexterity of performing movements with the affected hand increased.

IV. Conclusions

The proposed system was tested on healthy users and on a patient within clinical environment. The first feedback from the medics was that our device exceeds their expectations. Moreover, the system can be easily mounted on a patient's hand by a single physiotherapist in about 5 minutes. In order to achieve significant results, we plan to perform a clinical study on two groups of patients, a control group and test group. The control group will perform classical rehabilitation therapy while the test group will perform, in addition to the classical therapy, 25 sessions of training with the robotic glove, 5 sessions per week, each session lasting for about one hour. We also plan to improve the robotic glove structure for an easier and even faster mounting process on the patients hand and to add also bending sensors on all fingers in order to receive a more precise feedback regarding the movement of each finger of the affected hand.

Overall, the system makes the patients to be actively involved in their rehabilitation process, fact that may bring additional benefits to the outcome of the total rehabilitation process.

Acknowledgment

This work is supported by PCCA 150/2012 grant of the Executive Agency for Higher Education, Research, Development and Innovation Funding (UEFISCDI).

References

[1] World Health Organization: The top 10 causes of death. Available from: http://www.who.int/mediacentre/factsheets/fs310/en/

[2] Mehrholz J, Hädrich A, Platz T, Kugler J, Pohl M. "Electromechanical and robot-assisted arm training for improving generic activities of daily living, arm function, and arm muscle strength after stroke", Cochrane Database Syst Rev. 2012;6:CD006876.

[3] Kwakkel G, Kollen BJ, Krebs HI. Effects of robot-assisted therapy on upper limb recovery after stroke: a systematic review. Neurorehabil Neural Repair. 2008;22:111–121. doi: 10.1177/1545968307305457.

[4] Stein J., "Robotics in rehabilitation: technology as destiny". Am J. Phys Med Rehabil. 2012, 91:S199-S203.

[5] Chang W.H., Kim Y.H, "Robot-assisted Therapy in Stroke Rehabilitation", Journal of Stroke, 15(3): 174-181, September 2013.

[6] Varalta V., Picelli A., Fonte C., Montemezii G., La Marchina E., Smania N., "Effects of contralesional robot-assisted hand training in patients with unilateral spatial neglect following stroke: a case series study", J Neuroeng Rehabil, 2014, 11:160, 2014.

[7] Vanoglio F., Bernocchi P., Mule C., Garofali F., Mora C., Taveggia G., Scalvini S., Luisa A., "Feasibility and efficacy of a robotic device for hand rehabilitation in hemiplegic stroke patients: A randomized pilot controlled study", J. Clinical Rehabilitation, 2016.