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NEW FES-ROBOTIC GLOVE HYYBRID SYSTEM FOR HAND MOTOR FUNCTIONS REHABILITATION

BY

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Abstract. This paper presents the design and testing process of a hybrid FES-Robotic glove system intended for the hand rehabilitation process in post-stroke patients. The novelty brought by this system consists in the balanced control between the functional electrical stimulation used for artificially inducing the hand extensors contraction and the robotic glove that coordinates the proper finger movements. The robotic glove fingers are actuated by linear servomotors that are controlled by an Arduiono UNO microcontroller. This system has been tested on a healthy person in our laboratory and on a stroke patient within clinical environment.

Key words: stroke; rehabilitation; robotic therapy; functional electrical stimulation; linear servomotor.

1. Introduction

Nowadays, stroke became one of the main causes of disability in adults. The disability is caused by a motor or sensitive impairment, loss of interjoint coordination, spasticity and other pathological synergies that occur after stroke. In the last few years, the interest of using the robotic devices in neurorehabilitation has grown significantly. Different studies have shown that

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robot-assisted upper limb training can improve effectively the paretic arm functions while performing daily activities in stroke patients (Chang *et al.*, 2013; Kwakkel *et al.*, 2008; Mehrholz *et al.*, 2012; Stein *et al.*, 2012). Varalta and his colleagues (Varalta *et al.* 2014) have investigated the effects of hemi-spatial neglect of a training program based on contra-lesional robotic limb activation on 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 showed that robot assisted 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.

A more recent study (Vanoglio *et al.*, 2016) performed on 27 hemiplegic patients evaluated the feasibility and efficacy of a robot-assisted hand rehabilitation for improving the arm abilities. They divided the number of participants into two groups, 14 patients in the test group and 13 patients in the control group. Patients belonging to the test 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 but only with classical rehabilitation therapy. Even though the differences between the two groups were not statistically significant, they proved that using a robotic glove system is feasible and effective in recovering the fine manual dexterity and strength and in reducing the arm disability in sub-acute hemiplegic patients.

The current paper presents a new hybrid system for robot-assisted post-stroke rehabilitation, system that couples a robotic glove and the Functional Electrical Stimulation (FES) technology. The novelty brought in this field by our system is the balanced control between the electrical stimulation control for generating the muscle contraction and the robotic glove that coordinates the proper finger movements. Our system has been developed for 3 types of exercises: performing pre-defined movements, triggering a hand opening and closing movement by scanning the patient's intention to move and the third one allows mirror copying of the healthy hand movement by using an additional sensory glove. The system has been tested on a healthy person in our laboratory and on a stroke patient within clinical environment.

2. System Description

The robotic glove was special designed for a perfect fit on the paretic hand. It has metal tendons attached on the dorsal side for achieving active finger flexion and extension movements (Fig. 1). The FES stimuli, provided by a MOTIONSTIM8 neurostimulator (Krauth+Timmerman GmbH), are applied on the interosseous muscles and on the hand extensors, in order to induce a proper finger extension (Fig. 2).

Fig. 1 − Overview of the robotic glove with metal tendons attached.

Fig. 2 − Displacement of FES electrodes for achieving the fingers extension movement.

The device can assist the patient while performing three types of exercises. The first type uses pre-defined trajectories for each finger. The second type detects the patient's intention to move the paretic hand. By using a bend sensor attached to the middle finger of the robotic glove, the system triggers a pre-defined set of movements (fingers extension and flexion). The third type of exercise copies the finger movements of the healthy hand by using a data glove, a glove equipped with 5 bending sensors on each finger (Fig. 3).

Fig. 3 − Data glove – equipped with bending sensor on each finger.

The software controlling the entire system was developed under MATLAB&Simulink environment. It allows users to test and adjust the electrical stimulation parameters, pre-define different finger movements, selecting a certain exercise and to record the patient's performance like the number of movements for each finger, range and stimulation parameters for each session of treatment. Fig. 4 presents a schematic overview of the hardware system components, detailing at the same time the connections in-between them.

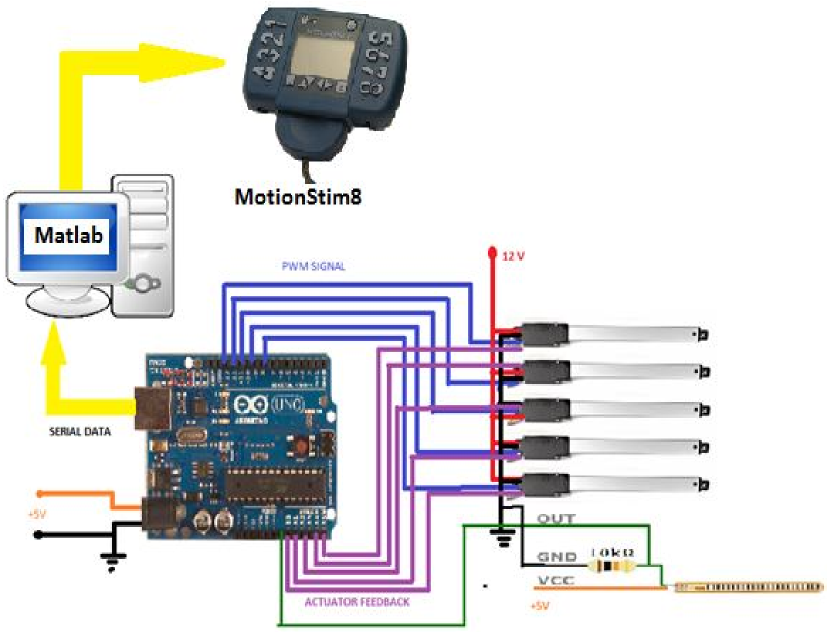

Fig. 4 − Schematic overview of the hardware components of the hybrid system.

Each finger of the robotic glove is individually controlled by a linear servomotor. The linear servomotors are controlled with pulse-width modulated signals generated by an Arduino Uno microcontroller. The signal provided by the resistive bend sensor attached to the middle finger of the robotic glove is read and converted to digital by the above mentioned microcontroller, and after sent to the computer.

The fingers position read by the sensory glove are read by the embedded microcontroller of the data glove and sent also to the computer where the main control strategy is implemented and that controls also the functional electrical stimulation.

For the second type of exercise, where the robotic glove movement is triggered by the patient intention to move the affected hand, the bending sensor placed on the middle finger has two roles: first – it is used for detecting the patient's intention to move the hand; second – detecting the fingers position while performing the pre-defined movements. Fig. 5 presents the output signal of the bending sensor attached to the robotic glove while scanning for the patient's intention to move the hand. The signal peaks are marked with red and the one that exceeds a pre-defined threshold is considered as trigger for the pre-defined movements. The threshold, figured with magenta solid line in Fig. 5 is calculated as 80% of the mean of the four highest peaks recorded during the calibration phase.

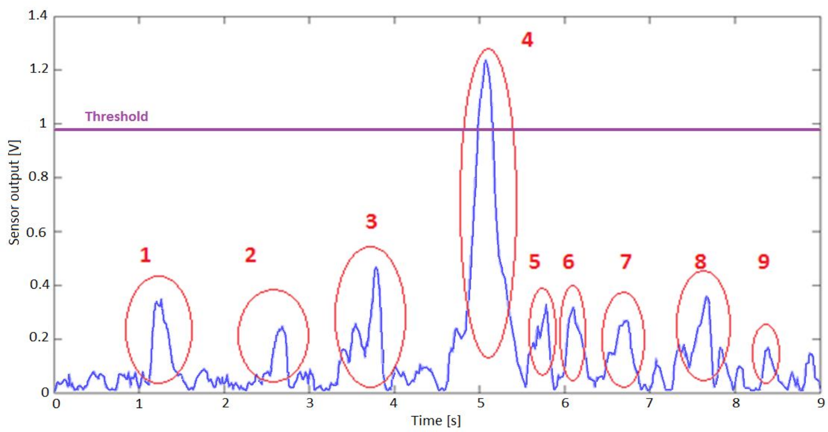

Fig. 5 – Output signal of the bending sensor attached to the middle finger of the robotic glove while scanning for the patient intention to move the hand.

Fig. 6 presents the sensor outputs of the data glove that was designed for the healthy hand while performing the third type of exercise – copying the healthy hand finger movements.

The problem that appeared in this type of exercise was the shaft positioning speed of the servomotor. When performing the finger flexion movement, action that naturally lasts from 1 to 1.5 seconds, the response time of the linear servomotors is almost 7 seconds. However, taking into consideration the facts that the system is intended to be used by stroke patients and that it is very important for them to perform slow movements, the response time of the linear servomotors is not representing a problem.

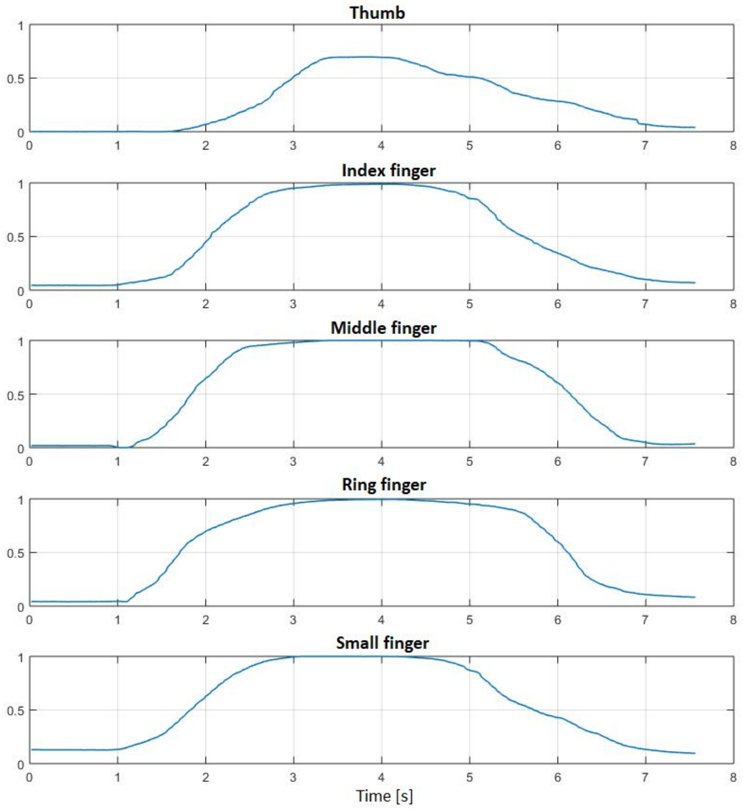

Fig. 6 − Data glove sensors output while performing flexion-extension exercises with the healthy hand.

3. Results

Before starting the tests within clinical environment, the ethical approval was achieved and the patient signed an informed consent before participating to the study. Up to now, we tested the system on a single patient. Fig. 7 presents the FES channels pulse widths and the bending sensors feedback for a time window of 100 seconds from the healthy hand copying exercise. The correspondence between the variations of the signals from the bending sensors placed on the healthy hand and the resistive bending sensor placed on the robotic hand can be clearly seen.

The time delay produced by the linear servomotors positioning disappeared because the fingers flexion and extension chained movements of the healthy hand were performed in concordance with the paretic hand movements. In the first plot of Fig. 7, the blue and red solid lines represent the pulse width values of the FES signals generated by channels 1 and 2 of the neurostimulator. The green solid line represents the middle finger position of the robotic glove.

The signal scaling was in %, where 100% corresponds to fingers totally flexed and 0% fingers totally extended. The second plot of Fig. 7 presents the signals generated by the data glove placed on the healthy hand, scaled in percent, with the same significance as the signal from the resistive bend sensor placed on the robotic glove.

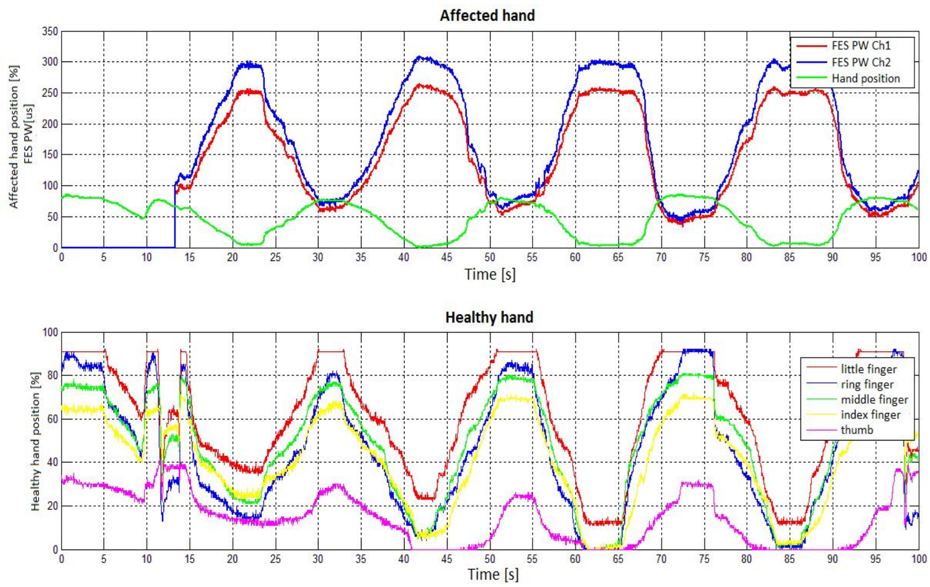

Fig. 7 − Stimulation pulse widths and data glove bending sensors feedback while performing healthy hand movement copying exercise.

The patient performed also the other type of exercise – triggering a pre-defined movement with the intention to move the affected hand. Fig. 8 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.

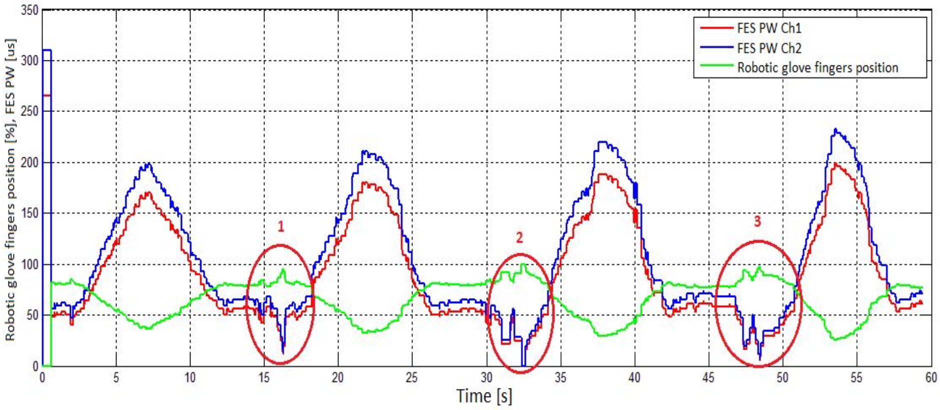

Fig. 8 − FES channels pulse widths and bending sensor feedback while triggering the pre-defined exercise with the intention to move the paretic hand.

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.

4. 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.

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SISTEM HIBRID FES-MĂNUŞĂ ROBOTICĂ PENTRU RECUPERAREA FUNCȚIILOR MOTORII ALE MÂINII

(Rezumat)

Lucrarea prezintă procesul de dezvoltare şi testare a unui sistem hybrid Manuşă robotică-FES, sistem destinat procesului de recuperare a mâinii în cazul pacienților care au suferit un accident vascular cerebral. Noutatea adusă de acest sistem constă în controlul balansat între stimularea electrică funcțională care induce în mod artificial contracția muşchilor extensori ai maînii, şi mănuşa robotică care coordonează efectuarea corectă a mişcării degetelor. Degetele mănuşii robotice sunt acționate prin intermediul unor servomotoare liniare controlate de un microcontroller de tipul Arduino UNO. Sistemul a fost testat în laborator pe o persoană sănătoasă, şi în mediu clinic pe un pacient.