Robot based Active Rehabilitation of the Hand

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***Abstract*— This paper describes different intelligent active modes to control an exoskeleton robotic device, devoted to the hand rehabilitation. A position-based control with EMG signals and mirroring technique has been implemented, with two different possibilities: triggered ON_OFF control and proportional control. The developed control permits to perform robotic aided exercises for the hand rehabilitation, leveraging the mirroring effect so as to obtain a better neuron-motor recovery. A preliminary study for a force based control has been conducted. The close correlation between the EMG signal and the pressure inside a bottle, grasped by the hand, allows to demonstrate the correlation between the EMG signal and the force exerted. The structure of the possible force-control mode is than presented.**

***Keywords*— Robotic Hand Rehabilitation, Electromyography, Intelligent active rehabilitation**

I. Introduction

Stroke is the leading cause of adult chronic disability in many western countries. An important topic of the rehabilitation research is to restore the motor abilities, and recent research is focused on hand recovery. Robotic aided rehabilitation demonstrated to be effective in hand rehabilitation [1]. A recent field of research is oriented to the application of surface ElectroMyoGraphy (EMG) in the active control of rehabilitative robotic devices [2,3]. GLOREHA (GLOve REhabilitation HAnd) is a device for neuron-motor rehabilitation that demonstrated to be effective for hand recovery. GLOREHA can be used in passive or active mode. This paper focuses the attention on two possible intelligent active modes. A Position Based Control (PBC) based on EMG signals and mirroring technique has been implemented and a preliminary study for a Force Based Control (FBC) have been developed. The block-diagram represented in Figure 1 can be used to describe the related procedures.

II. Active control of the rehabilitation robot

Position-based control (PBC)

PBC consists in the execution of openings and closures of the impaired hand, controlled by the corresponding opening and closing of the healthy hand, to create a mirroring effect. The goal is to recover the hand abilities and to stimulate the reorganization of the associated neural connections. The activity of the healthy hand is detected by the EMG signal measured by five electrodes. We used two electrodes (E1, E2) placed over the extensor digitorum and the extensor carpi radialis to measure the muscle activation during the extension. Whereas, to detect muscle activation during flexion, we placed two electrodes (E3, E4) over the palmaris longus and the flexor carpi ulnaris. One electrode (Er) was used as reference. The first module in Figure 1 measures EMG signals, conditions them and also filters out noises. Subsequently, the filtered EMG signals are sent to the feature extraction module to identify the parameters used in the control algorithm. A Personal Computer (PC), with a properly developed software, is used to implement the blocks 1 and 2. Using the extracted features, a second software, determines the hand movements and generates adequate commands to control the robotic glove.

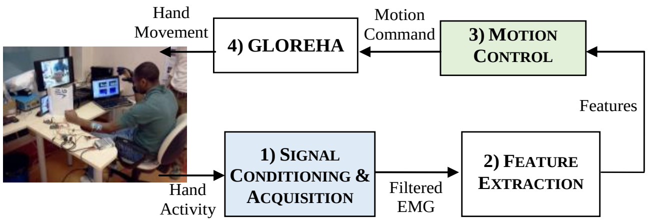

Fig. 1. *Block-diagram of the proposed procedure of rehabilitation.*

The feature used is the Root Mean Square (RMS) of the EMG signal, that could be more appropriate to generate the control signal than the envelope of the rectified EMG signal [12]. Figure 2 compares the EMG raw signal for hand closing (flexion, red) and for hand opening (extension, blue) with the respective more usable RMS values (FLX_{RMS} and EXT_{RMS}, respectively).

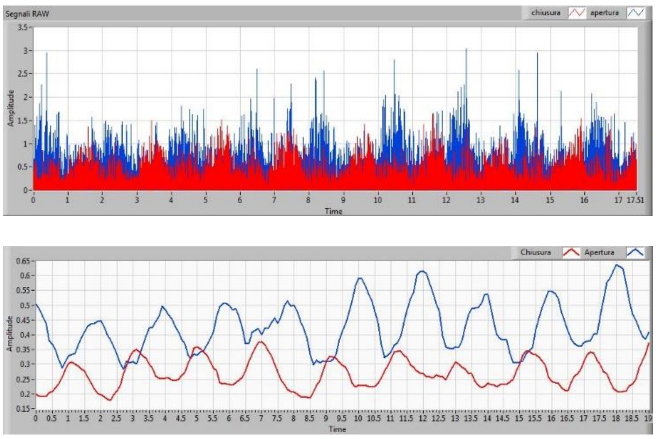

Fig. 2. *Comparison between raw signals and RMS feature.*

To control GLOREHA we use the difference (D) between the FLX_{RMS} and the EXT_{RMS}, the latter multiplied by a gain factor G to make it comparable to the former (Eq.1). The dynamic behaviour of an industrial robot is described by the following matrix equation:

$$D_{RMS} = EXT_{RMS} - G \times FLX_{RMS} \quad (1)$$

Two kinds of PBC have been considered: triggered ON-OFF control and proportional control. In the triggered ON-OFF control, two thresholds (T_{min} and T_{max}) are needed to detect “Hand Opening”, “Hand Rest” and “Hand Closing”

(Figure 3). For the proportional control, four thresholds (T_1, T_2, T_3 and T_4) are needed; two to define the dead band in which EMG_{RMS} values do not produce any unwanted motor motion (T_1 and T_4), the others (T_2 and T_3) to obtain a control command S (eq.2) proportional to the D signal.

$$S = \begin{cases} S_{\max}, \ if \ D_{RMS} > T_4 \\ \dfrac{S_{\max} - S_{\min}}{T_4 - T_3}(D_{RMS} - T_3), \ if \ T_3 < D_{RMS} < T_4 \\ 0, \ if \ T_2 < D_{RMS} < T_3 \\ \dfrac{S_{\max} - S_{\min}}{T_1 - T_2}(D_{RMS} - T_2), \ if \ T_2 < D_{RMS} < T_1 \\ S_{\min}, \ if \ D_{RMS} < T_1 \end{cases} \quad (2)$$

An auto-tuning algorithm for the evaluation of the thresholds has been developed, starting from recorded EMG signal in a preliminary phase of system tuning. Figure 4 reports an example of the approach for the thresholds automatic identification used. The 1st, and 99^{th} percentile of the amplitude probability distribution (APD) of the D_{RMS} signal are chosen as values for T_1 and T_4. The 35^{th} and 80^{th} percentile of the APD of D_{RMS} are assigned to T_2 and T_3, which identify the rest phase.

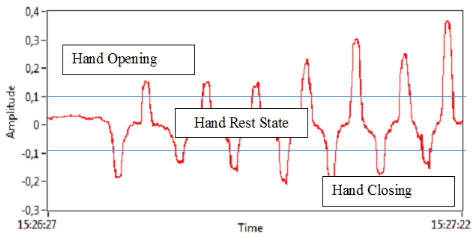

Fig. 3. *Example of thresholds on EMG_{RMS} signal in the triggered ON-OFF control.*

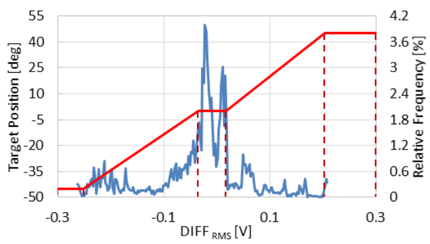

Fig. 4. *Example of thresholds evaluating in the proportional control (blue: D_{RMS}.ADP; red: related computed S function).*

Figure 5.a shows the trends of the EMG signal, the D_{RMS} signal and the movement of the actuators relative to a test with triggered ON-OFF control, whereas Figure 5.b the evolution of the same quantities in a test with proportional control.

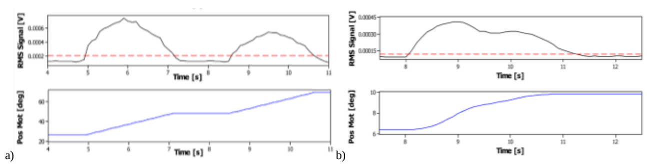

Fig. 5. *a) Example of triggered ON –OFF control; b) Example of proportional control. Above the D_{RMS} signal, below the motor movement.*

Force-based control (FBC)

The force-based control is thought to recover the functional tone of the diseased limb. It is based on the use of the amplitude of the EMG signal as an indicator of the force exerted by the subject. We measure the EMG signal of flexion on both the arms, extract from them a feature proportional to the force (F_{healt} and $F_{impaired}$) and move the actuator delivering a force in relation to the difference between F_{healt} and $F_{impaired}$. To study the correlation between the EMG signal and the force exerted by the subject, opening and closures tests were carried out by gripping a preloaded under pressure plastic bottle and measuring the pressure in the bottle during gripping Pressure and EMG signals are normalized to make them comparable. Tests on ten different healthy subjects were performed with a sequence of openings and closures. Figure 6 shows the normalized RMS of the EMG signal and their derivative obtained in a test with one of the considered subjects.

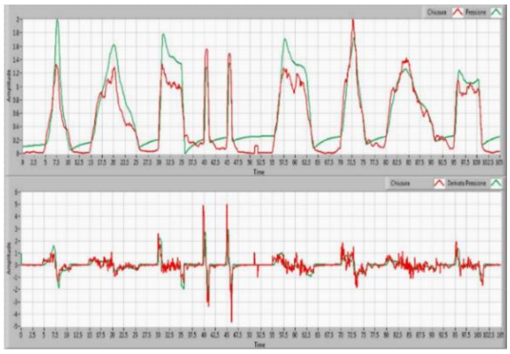

Fig. 6. *First line: RMS of the flexion EMG signal and normalized pressure signal. Second line: derivative of normalized signals.*

From all the carried on tests we deduce that the RMS of the flexion EMG signal and the pressure signal have a similar pattern, the amplitude of the signals varies from person to person, the RMS signals of subjects is related to the BMI (Body Mass Index).

III. Conclusions

The developed triggered ON_OFF and proportional PBC permit robotic aided exercises, leveraging the mirroring effect. The tests performed showed a close correlation between the pressure and the EMG signals. This result can be used to develop a FBC based on EMG. The EMG signal of the healthy hand can be used as a reference for maximum developable force. The force exerted by GLOREHA during the movement may be related to the difference between the RMS intensity of the EMG signal detected on the healthy limb and that detected on the impaired limb. Thus, with the progress of the recovery, GLOREHA would gradually reduce the contribution of force to the movement. A future development foresees that the system, based on the data collected in various rehabilitation sessions on different people, develop optimal strategies, based on artificial intelligence tools for data analysis.

References

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