An EMG-based robotic hand exoskeleton for bilateral training of grasp

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ABSTRACT
This work presents the development and the preliminary experimental assessment of a novel EMG-driven robotic hand exoskeleton for bilateral active training of grasp motion in stroke. The system allows to control the grasping force required to lift a real object with an impaired hand, through the active guidance provided by a hand active exoskeleton, whose force is modulated by the EMG readings acquired on the opposite unimpaired arm. To estimate the grasping force, the system makes use of surface EMG recordings during grasping, developed on the opposite unimpaired arm, and of a neural network to classify the information. The design, integration and experimental characterization of the system during the grasp of two cylindrical objects is presented. The experimental results show that an optimal force tracking of the interaction force with the object can be achieved.

Index Terms: [Human-centered computing]: Human computer interaction (HCI)—Interaction devices: Haptic devices; [Applied Computing]: Life and medical sciences—Health informatics

1 INTRODUCTION
Recent studies estimate that stroke affects approximately 795 000 people in the U.S. each year [1]. One of the most common and challenging outcomes after stroke is the impairment of upper limb function, that limits the patient’s autonomy in daily living and may lead to permanent disability. The motor impairment typically includes weakness of specific muscles or abnormal muscle tone. An intensive and prolonged robotic-assisted training has been shown to reduce motor impairments and lead to positive effects in terms of motor recovery [2], that can be interpreted in terms of re-learning of motor strategies at neural central level.

One of the promising techniques in stroke rehabilitation is represented by bimanual training [3], which recently emerged in the battery of tools used in neuro-rehabilitation [4].

Bimanual tasks require to operate the two hands together, so that they cooperate to accomplish the aimed function. In everyday life, it turns out that this cooperation is often asymmetric, with the dominant hand playing a manipulative role, when the other hand manages further stabilization [5]. Yet, this co-operation of the two hands naturally falls into one of two types of coordination: either the simultaneous activation of homologous muscles (in phase coordination), or alternating activation of homologous muscles (anti phase coordination).

Bimanual training builds on natural inter-limb coordination principles to favour motor recovery [6]. In a bimanual task, both upper limbs influence (and are influenced by) each other, so that it becomes possible that the non-paretic limb entrain the paretic limb and improve its output [7]. Bimanual training is strongly justified on neurological bases. First, the observed automatic coordination of the two hands is supported by the existence of specific neural pathways [8] and these pathways are activated simultaneously in both hemispheres during bimanual training [9]. Second, brain plasticity is driven by the nature and the amount of training, so that bilateral training induces reorganisation in cortical networks [6]. Moreover, an important functional argument favouring bimanual training is that it is closer to activities of daily living than unimanual practice, in the face of the high number of bimanual tasks in activities of daily living. When used for the analysis of bimanual training in stroke patients, kinematic studies indicate that training patients with two-handed tasks improve the efficiency of grasping movements on the impaired side [10] and that these changes are accompanied by a reorganization of brain mappings on the affected hemisphere.

Bimanual training encompasses several techniques, all of them requiring the simultaneous use of both upper-limbs [11]: bilateral isokinematic training; mirror therapy using bilateral training; device-driven bilateral training; and bilateral motor priming. This kind of intervention can be practically implemented with robotic devices, such as arm exoskeletons or hand othosis. In [12] the authors already proposed a haptic bi-manual system for rehabilitation training in stroke.

In this work, we focus on a specific rehabilitation scenario, that is the rehabilitation of hand grasping of objects which falls within the activities of the BRAVO project [13]. It is well-known how stroke patients exhibit difficulties in adjusting the proper grasping force required to lift an object [14], for which systems already supporting the training of grasping have been initially proposed and developed [15].

Figure 1: Conceptual scheme of the proposed system.

In this study, we propose a novel system for EMG-based robotic-assisted bilateral hand training (see Fig. 1). In the proposed rehabilitation scenario, the unimpaired patient’s hand can act as master providing a guidance to the impaired hand in grasping tasks, by means of an active hand orthosis, through the interpretation of EMG surface activity recorded on the forearm of the opposed unimpaired