Bilateral Rehabilitation of Hand Grasping with an Underactuated Hand Exoskeleton

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***Abstract*— In this work we present a bilateral rehabilitation system for the hand based on a novel underactuated hand exoskeleton to assist hand opening/closing and a pair of pressure-sensorized graspable objects. In particular the novel hand exoskeleton provides self-adaptability to different hand sizes and a more effective transmission of forces. In the system, the grasping force measured at the healthy side is used to modulate the assistance of the hand exoskeleton at the impaired side. Utilizing simpler and more reliable pressure-sensorized graspable objects instead of biosignals might allow the system to adapt to residual motor capabilities of the impaired hand. System performance of the robotic assisted, bilateral grasping tasks have been experimented with 3 healthy subjects.**

I. Introduction

Physical rehabilitation is an indispensable solution for treatment of neurological injuries, such as stroke [1], [2]. Engaging with daily activities helps to restore functionality in individuals with injured hands and provides a platform to practice selected occupations. Bimanual training is a rehabilitation strategy based on natural inter-limb coordination [3]. Training patients with two-handed tasks improves the efficiency of grasping movements on the impaired side [4] with changes accompanied by a reorganization of brain mappings on the affected hemisphere.

Robotic rehabilitation with bilateral approach provides reliable signals from the healthy limb that can be used to drive the robotic tool, which assists the affected one. A common way to perform such a bilateral control is to utilize Electromyography (EMG) sensors [5], [6]. However, using such a wearable sensor might require long preparation time and calibration for each patient and session. In [7] the use of pressure-sensorized graspable objects was proposed to assist grasping in a robotic rehabilitation scenario. In this study, we propose a bilateral rehabilitation system for the hand based on a novel underactuated hand exoskeleton (HandExos [8], [9]) and a pair of customized graspable objects provided with pressure sensors. The aim of the rehabilitation system is to assist patients in performing bilateral grasping tasks by means of a simple and reliable setup, including an underactuated active hand exoskeleton. The sensorized objects measure the grasping force of both the healthy and affected hands, while the HandExos assists the affected hand to replicate the grasping force at the healthy side. We evaluated the rehabilitation system performance and the capabilities of the HandExos in experiments enrolling 3 healthy subjects.

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II. Materials and Methods

The proposed bilateral rehabilitation system using pressure sensorized objects and the HandExos is shown in Fig. 1.

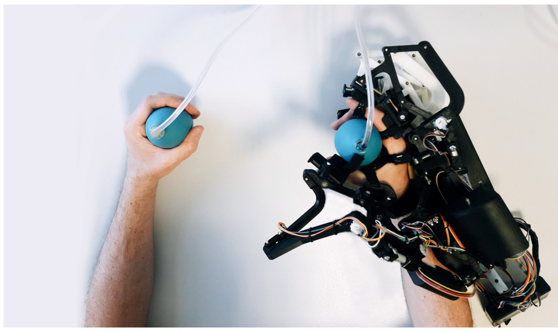

Fig. 1: The proposed bilateral rehabilitation system: the HandExos and the two sensorized objects.

Two identical rubber pumps with pressure sensors (MPX4250A, range 20250 kPa; sensitivity 20 mV/kPa) have been used to measure the grasping forces at both healthy and impaired sides. The sensors are read through the control board with sample rate of 100 Hz.

HandExos, recently developed by our group, has been used to assist user's impaired hand. By means of a peculiar kinematic design, HandExos provides self-adaptation to different hand sizes, moreover it provides a more effective transmission of actuators' forces to fingers (only forces perpendicular to the phalanx axes).

III. Experimental Methods and Results

Details of the experimental scenario are shown in Fig. 2: subjects were asked to hold sensorized objects in both hands, with the exoskeleton worn on the right one. Subjects were asked to squeeze the object by their left hand, generating a pressure reference P_{ref}. A variable pressure profile was also defined for subjects to follow as a visual reference, such that the given task could be repetitive. Meanwhile, subjects were asked to relax the right hand, where the hand exoskeleton is attached to. Relaxed right hand was guided by the exoskeleton in order to squeeze the sensorized object, thus generating the output pressure P_{out}. P_{err} was defined as the difference between the pressure reference P_{ref} and the output pressure P_{out} was used to control the actuator forces F_{ref} in order to match the two pressures.

The proposed experimental scenario was designed to be used by patients with hand disabilities, yet the preliminary tests presented in this work have been performed by 3

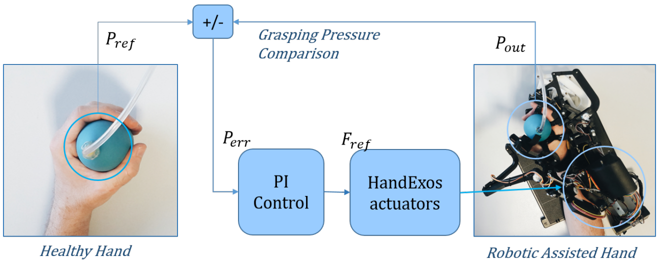

Fig. 2: The control algorithm of the proposed rehabilitation scenario: the exoskeleton is actuated to minimize the difference between readings of two pressure sensors attached on the sensorized pumps.

healthy subjects (ages 30 $\pm$ 2), providing informed consent to participate. With the described configuration, two different pressure profiles characterized by different maximum pressure levels have been visually provided to the subjects during the experiment. Each subject performed 10 grasping repetitions for each of the proposed pressure level.

Graph in Fig. 3 (left) shows the pressure profile measured for the left (unimpaired/unassisted) hand (LH) and robotic assisted right hand (AH) respectively, over the time span of a single grasping and opening repetition. Pressure profiles have been averaged over trials and subjects. The pale colored area shows the standard deviation, while the black dotted lines represent the two different references subjects were asked to follow through the left (unassisted) hand. Finally, Fig. 3 (right) shows the Bilateral Grasping Error, evaluated as the difference between grasping pressure measured at the left and right hand. Results show overall good performance of the system in assisting the relaxed hand to match the reference pressure P_{ref}. Repeatability of the system behavior among repetitions and subjects was relatively high considering amplitude of the mean error and standard deviation reported in Fig. 3 (right) and compared to the amplitude of the provided pressure profile shown in the same figure (left).

IV. Discussions and Conclusion

In this paper, we proposed a bilateral rehabilitation scenario for the treatment of hand disabilities. The proposed control system actuated a robotic hand exoskeleton in order to match the grasping force between the assisted and the active hand of the user, while performing symmetrical grasping tasks. This work proposes the use of a novel underactuated hand exoskeleton and of a simpler and more reliable setup based on pressure-sensorized objects for estimating the grasping forces. The initial trials with healthy subjects showed that such system could effectively assist the relaxed hand of the user to mimic the healthy hand, envisaging its application in bilateral rehabilitation therapy. Importantly, the use of pressure-sensorized graspable objects and the implementation of the control loop at the level of the measured grasping pressure, allow the system to automatically adapt the robotic assistance to the residual forces exerted by the patient (both for hand grasping and relaxation). Although such relevant features was not possible

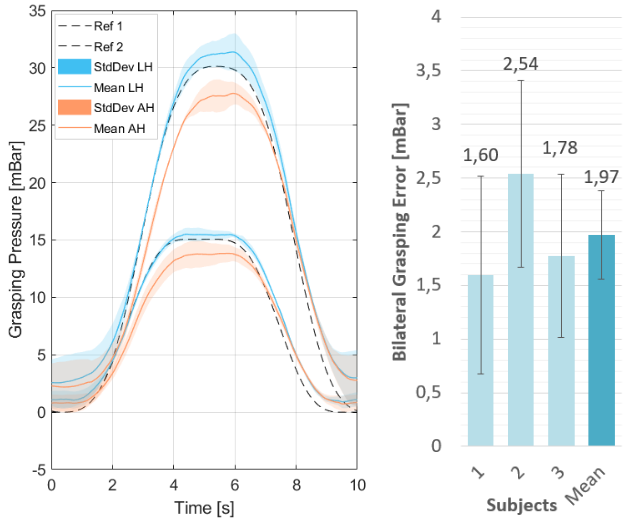

Fig. 3: (left) Profile over time, averaged over repetitions and subjects, of the grasping pressure measured at the left (healthy) hand LH and right (robotic assisted) hand AH. (right) Grand average of the Grasping Pressure Error (difference between grasping pressure measured at the left hand and at the right hand).

to be tested in the presented work with healthy subjects, in future works we expect to test usability and performance of the proposed system and of the novel hand exoskleton with patients presenting different motor outcomes.

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