Development of a Wearable Exoskeleton for Hand/Wrist Rehabilitation and Training

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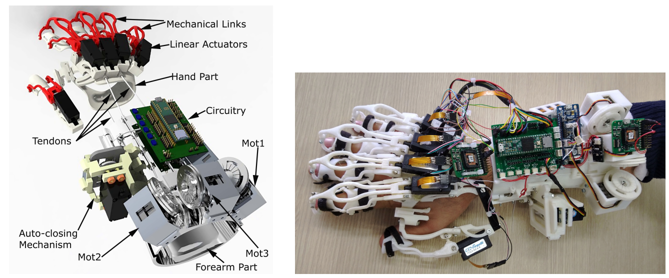
***Abstract*—Robot rehabilitation is an emerging and promising topic that incorporates robotics with rehabilitation and neuroscience to define new methods for supporting patients with diseases. The rehabilitation process could increase the efficacy exploiting the potentialities of robot-mediated therapies. In this paper we propose an innovative exoskeleton for wrist and hand motion training. It is designed to be wearable, easy to control and manage. It can be used by the patient in collaboration with the therapist or autonomously. The paper introduces the main steps of device design and development and presents some possible exercises that can be performed by a user with limited wrist mobility.**



(a) (b)

Fig. 1: Hand and wrist exoskeleton (a) CAD model. (b) Prototype worn by a user.

I. Introduction

At the beginning of 2020, COVID-19 pandemic dramatically modified most of our habits, including medical and rehabilitation practices, that necessarily had to be delivered remotely, through audiovisual technology. Orthopedic and rehabilitation also shifted from face-to-face visits to audiovisual-guided sessions. In the immediate future, telerehabilitation could further spread and become more common. Despite some limitations, there are evident advantages in distance rehabilitation, whether synchronous (real-time) or asynchronous (store-and-forward). The implementation of telehealth rehabilitation, which was initially considered difficult or even impossible, now has been forced to be utilized widely [1].

More in general, nowadays, most of the people are living a longer and healthier life than in the past, as the mean age of the population increases, and, as a consequence, the overall social impact of chronic diseases related to the musculoskeletal and nervous system becomes more important. The World Health Organisation (WHO) statistics show that nearly one billion people worldwide are suffering due to the neurological and musculoskeletal diseases [2]. On the other hand, the spreading of technology in everyone everyday life is playing an important role in preserving and guaranteeing a high quality of life also in presence of temporary and/or permanent diseases.

The upper limb plays an important role for all daily activities, and various exoskeleton devices have been already developed as support tools for this part of the body [3], [4]. In particular, different devices are specifically developed for the wrist [5] and for the hand [6]. Not withstanding the technological developments and the evidence of clinical effectiveness of robotic technologies for upper-limb neuro-rehabilitation, there are still some limits in their diffusion [7]. Technological and economic barriers together with communication biases between the producers of the technologies are still open issues.

In this paper we propose an exoskeleton for hand and wrist motion assessment and training (Fig. 1). The device has been designed starting from the user's point of view, to be easily and autonomously wearable, easy to control and manage, modular and versatile. The device can be used by the patient in collaboration with the therapist or autonomously, and is composed of two independent and modular elements: the wrist actuation and the hand actuation systems.

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II. Device presentation

Wrist actuation: The proposed solution for the wrist consists in a tendon actuated module comprising two main elements worn on the hand and on the forearm, respectively. Tendon actuation simplifies the mechanical structure, so that the number and weight of components has been limited as much as possible. The forearm exoskeleton structure can be adapted to the user's specific needs. In the first prototype of the device, introduced in [8], the exoskeleton was fixed on the forearm by means of two Velcro belts. Although the system is simple and low cost, it is not suitable for users with limited motion capabilities and could result in undesired motions. An automatic closure system, actuated by two servomotors, has been then developed.

Hand actuation: Regarding hand actuation, the proposed has been developed to control each finger independently. The modules for index, middle, ring and little fingers have the same mechanical structure, with different dimensions, thumb module has a different mechanism, due to the particular kinematic structure of the digit. To reduce the inertia, we positioned the actuators on the back of the hand and the motion is transmitted to the joints through a proper transmission system. The proposed solution, preliminarily introduced in [9], has only one motor per finger, that actuates both the proximal and intermediate phalanges, and is able to apply

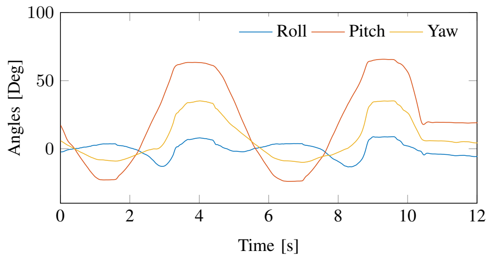

Fig. 2: Example of data recorded during a wrist exercise. Roll, pitch, yaw angles measured by the tracking system during a Flexion/Extenstion representative trial.

bi-directional forces. The mechanical transmission has been developed to implement the simplifying concept of the first postural synergies, introduced by the neuroscientific studies presented in [10].

Tracking: Since the wrist exoskeleton hand and arm elements are not mechanically constrained, a key aspect for controlling the device is represented by the tracking of hand/arm movements. The proposed solution for the tracking system is based on multiple Inertial Measurement Units (IMUs), low-cost electronic devices integrating an accelerometer and a gyroscope on a single board. More in detail, we developed data acquisition and processing of IMU sensors, their translation in biomechanical information and online data monitoring. The resulting system is able to: *i)* record the user's motion (*e.g.* exercises suggested and guided by the physiotherapist); *ii)* monitor/control exercises guided by the exoskeleton; and *iii)* analyze patient's range of motion and consequential improvements. Regarding the hand actuation system, since finger motion is constrained by exoskeleton mechanical structure, hand configuration is directly related to actuator displacements, by means of standard forward kinematics relationships.

Implementation and control: Both the hand and the wrist actuators are position controlled. The proportional gain can be selected in a predefined range to regulate the stiffness of the device. The input for the control scheme is the desired movement $\boldsymbol{\theta}_{des}$, that can be assigned by the user through the graphical user interface or previously recorded by the tracking system. $\boldsymbol{\theta}_{des}$ values can be recorded for example during the execution of an exercise in which the exoskeleton is not actuated and the hand and wrist motions are manually guided by the physiotherapist, or can be loaded from an exercise database by means of user interface. Through inverse kinematic analysis, desired configurations are transformed in references for the actuators control systems $\boldsymbol{q}_{des}$. Actual hand and wrist movements $\boldsymbol{\theta}$ are monitored by the tracking system during exercise execution, displayed on the user's interface and logged.

User interface: A Python Graphical User Interface has been developed to set exercise parameters and monitor them. When opening the application, the device has to be connected to the user's control device through the Bluetooth module. Once the exoskeleton is connected, the user can set a home position, or initiate the exercise. Moreover, the user can select between an automatic, manual or "learning mode" device control. Some exercises are already available in the interface, in particular the typical wrist exercises, like flexion/extension and abduction/adduction motions. For each exercise, the user can select three different speeds (low, medium and high) and a running time. In a successive phase of the work, an *ad-hoc* App for the most common smart-phones or tablets will be developed and released, to improve the accessibility for the users.

Tests and evaluation: The system was evaluated on different subjects, both healthy and with limitations in arm/wrist motion. The tests were aimed at verifying the performance of the device in terms of accuracy in the execution of specific exercises. Different typologies of exercises suggested by the physiotherapist, involving both the hand and the wrist, are tested. As an example, Fig. 2 represents roll, pitch, yaw angles estimated by the IMU based tracking system during a Flexion/Extension wrist exercise.

III. Concluding remarks

Nowadays, research on the use of robotic systems in different fields related to healthcare is widespread and interesting solutions are available in the literature. The availability of more autonomous and intelligent processes in neurorehabilitation could increase the effectiveness of rehabilitation process, since it would allow to increase the frequency of the exercises, reduce the costs for the patient and for the overall healthcare system. In this paper we present an exoskeleton designed and developed for hand and wrist exercises. The main features of the developed device are: light weight, wearability and adaptability, ease of use. There are still some barriers in the diffusion of robotic systems in the daily life of the people, due to their complexity and costs, our work aims at reducing some of them.

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