Design and Motion Analysis of a Wearable and Portable Hand Exoskeleton

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Abstract The design of an aid for the hand function based on exoskeleton technologies for patients who have lost or injured hand skills, e.g. because of neuromuscular or aging diseases, is one of the most influential challenge in modern robotics to assure them an independent and healthy life. This research activity is focused on the design and development of a low-cost Hand Exoskeleton System (HES) for supporting patients affected by hand opening disabilities during the Activities of Daily Living (ADLs). In addition, the device, able to exert suitable forces on the hand, can be used during the rehabilitative sessions to implement specific tasks useful to restore the dexterity of the user's hand. The validating and testing phase, conducted in collaboration with the Don Carlo Gnocchi Foundation, showed satisfying results both in terms of portability and wearability which are fundamental requirements for assistance during the Activities of Daily Living (ADLs) and for rehabilitation of people with hand impairments.

1 Introduction

Nowadays, the first cause of adult disability in Europe is the Cerebral Vascular Accident (CVA) [1]. Up to 80 % of post-stroke patients suffer from hemiparesis of the upper arm. Moreover, the number of patients with a disability in the upper part of the body is rising together with the number of elderly [2], who will constitute, in a

A special thanks goes to the Don Carlo Gnocchi Foundation, where the validation phase of the research activity has been carried out and the testing phase is currently ongoing.

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J. González-Vargas et al. (eds.), *Wearable Robotics: Challenges and Trends*,
Biosystems & Biorobotics 16, DOI 10.1007/978-3-319-46532-6_61

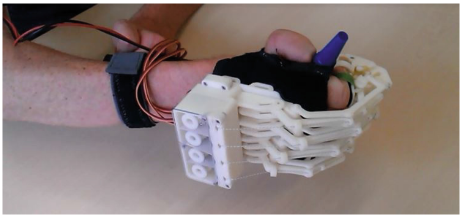

Fig. 1 The low-cost hand exoskeleton developed by the MDM Lab

few years, more than the 30 % of the total population. Post stroke survivors, genetic disease patients and elderly with hand disease need timely and persistent rehabilitative training to regain previously dexterity and an assistance during the Activities of Daily Living (ADLs). An effective and specific solution for the aforementioned patients may be provided by the use of robotic devices. In fact, robotic systems allow to provide prolonged and higher-intensity rehabilitation treatments, with a reduction of costs and burden for the therapists [3]. Since such devices [4] are designed to be used during rehabilitative sessions, their portability requirement is not mandatory, as they are employed in hospitals, rehabilitation centers or at home in a specific location dedicated to their utilization [5, 6]. In case the hand functions may not be totally restored even after an intense rehabilitation process, hand exoskeletons can be used to support the user in ADLs assisting the hand performance by amplifying the hand gripping force [7] or automating the motion [8]. In this case, the wearability of the device is essential as it must be worn for a long time during the day. Basing on strict requirements of wearability, portability, cheapness and modularity, the researchers of the Mechatronics and Dynamic Modeling Laboratory (MDM Lab) of the Department of Industrial Engineering of the University of Florence (DIEF) have developed and tested an assistive and rehabilitative device for hand disabilities [9] (Fig. 1). This robotic orthosis is designed to be a low-cost and portable hand exoskeleton for patient's assistance and for rehabilitative use. If compared to the current state of the art [10, 11], the proposed novel mechanism results easily adaptable to different hand sizes by modifying only a few geometrical parameters. In addition, the device is specific for the hand anatomy of the user and is able to closely follow the trajectories of all the long fingers.

2 Design Phase

The design of the mechanism and the choice of the actuation system have been performed in parallel with the development of the 3D multibody model of the exoskeleton (which includes the hand model): this model-based approach allows the authors to optimize the wearability of the system.

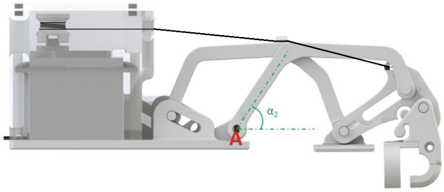

Fig. 2 Exoskeleton mechanism parts

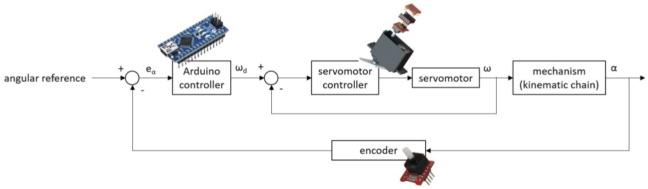

Fig. 3 Closed-loop angular control of the device

A. Mechanical Part

Starting from the 3D multibody model, a novel exoskeleton kinematic chain, based on a 1 Degree Of Freedom (DOF) mechanism (Fig. 2), has been designed to reproduce the desired trajectories of the fingers. The hand exoskeleton mechanism has then been optimized to reduce both the lateral and the height encumbrances and, finally, all the parts have been built and assembled. The device is mainly realized in Acrylonitrile Butadiene Styrene (ABS) and all the structural components have been built by means the 3D printer of the MDM Lab.

B. Electronics

The electronics consists of four independent servomotors (one for each finger, placed on the back of the hand), a control unit and a battery pack. The characteristics of the servomotor, in terms of torque, size and weight, have been chosen according to the results of numerical simulations. Using a 15-bit magnetic encoder placed on the joint A of the Fig. 2, the value of the angle α_2, which identifies the single DOF of the mechanism, can be measured. Using this angular information, a closed-loop angular control of the mechanism is realized by means of an Arduino single-board microcontroller (see Fig. 3 for the control loops architecture). The opening and closing gestures are commanded using buttons.

3 Results

This phase of the research activity consists in the evaluation of the transparency of the HES (the capability of the device in reproducing the real trajectories of the hand phalanges) for a particular test case (a patient suffering from Spinal Muscular

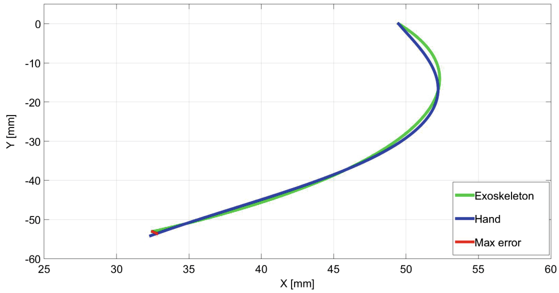

Fig. 4 Comparison between the finger (*blue*) and exoskeleton (*green*) trajectories

Atrophy) and it has been executed using a Motion Capture (MoCap) system. The motion analysis was carried out by means of the optoelectronic system made up of 3 cameras. The system (BTS SMART-Suite Motion Capture System by BTS Bioengineering S.p.A., Milano, Italy) is able to automatically record 3D trajectories of passive markers Fig. 4 reports the comparison between the trajectories of the contact point between the hand and the end effector of the device for the index finger. In particular, the blue line is the trajectory of the index finger acquired through the MoCap system, while the green one is the trajectory of the mechanism end effector (also this trajectory is acquired by means the SMART-DX system) when the device is not worn by the user. The kinematic behavior of the device is very close to the natural one; in this case, the maximum error is 0.57 mm (red line in Fig. 4).

4 Conclusion

In this work the development and the testing phase of a portable HES for assisting people with hand opening disabilities have been presented. The comparison between the real phalanx and the mechanism trajectories provides very satisfying results in terms of trajectory agreement, highlighting the transparency of the mechanism with respect to the users general movements. At the time of writing, several exoskeleton devices are involved in the testing phase on patients at the Don Carlo Gnocchi Foundation Rehabilitation Center, Florence, Italy. These exoskeletons present a reduced weight, less than 500 g, and they proved to be very comfortable for the users.

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