A novel architecture for a fully wearable assistive Hand Exoskeleton System

1st Nicola Secciani
Department of Industrial Engineering
University of Florence
Florence, Italy
nicola.secciani@unifi.it

2nd Marco Pagliai
Department of Industrial Engineering
University of Florence
Florence, Italy
m.pagliai@unifi.it

3rd Francesco Buonamici
Department of Industrial Engineering
University of Florence
Florence, Italy
francesco.buonamici@unifi.it

4th Federica Vannetti
IRCCS Don Gnocchi
Don Carlo Gnocchi Foundation
Florence, Italy
fvannetti@dongnocchi.it

5th Yary Volpe
Department of Industrial Engineering
University of Florence
Florence, Italy
yary.volpe@unifi.it

6th Lorenzo Bartalucci
Department of Industrial Engineering
University of Florence
Florence, Italy
lorenzo.bartalucci@unifi.it

7th Andrea Della Valle
Department of Industrial Engineering
University of Florence
Florence, Italy
andrea.dellavalle@unifi.it

8th Benedetto Allotta
Department of Industrial Engineering
University of Florence
Florence, Italy
benedetto.allotta@unifi.it

9th Alessandro Ridolfi
Department of Industrial Engineering
University of Florence
Florence, Italy
alessandro.ridolfi@unifi.it

***Abstract*—Robotics for Medicine and Healthcare is undoubtedly an important emerging sector of the newborn third millennium. There are many aspects in which this branch of robotics already operates; in this article, the focus will be on the so-called “Robotic assistive technology”. In particular, a novel electromechanical design for an assistive Hand Exoskeleton System is presented here. Since freedom of movement plays a crucial role in making actually usable an assistive device, the main point of innovation of the proposed solution lies in the complete wearability of the resulting system: including mechanics, control electronics, and power supply. From the combination of the authors’ previous experience with the improvements presented in this article comes a fully standalone tailor-made assistive device.**

***Index Terms*—Hand Exoskeleton, Wearable Robotics**

I. INTRODUCTION

The demographic, economic, social, technological, environmental, and political factors (DESTEP factors) of the last decades of the 20th century and the first years of 21st century have paved the way to the advent of the Robotics for Medicine and Healthcare as a potent tool to overcome the availability limits of the standard Assistive Technology (AT) [1]. By looking at the state of the art, it is easy to recognize the typical signals of a sector in great ferment, where many different solutions are continuously proposed. Within the myriad of innovative devices that literature offers, a place of honor is, nowadays, indeed reserved for hand-assistance devices. The main reason is that, when it comes to restoring at best the quality of life to people with disabilities, it is mandatory to focus on the hand.

Although there is a large number of alternatives in the literature, it is not easy to find a fully wearable solution that does not constrain the wearer to a fixed or bulky actuation system, or an external data processing unit [2], [3]. Freedom from both types of equipment is non-negligible when it comes to assisting people in everyday life. In this paper, the authors describe a new design of a Hand Exoskeleton System (HES) developed to fill the gap mentioned above, still very present in the state of the art, embodying a fully wearable robotic device for impaired-hand assistance. The strengths and flaws of such a solution will be discussed in detail.

II. THE NEW ARCHITECTURE

This section is entirely dedicated to the description of the changes that have been made to solve the problems highlighted by a pilot study on previous prototypes [3].

A. sEMG technology

During the assessment of the previous prototypes usability it has been seen that the wrist movements could sometimes establish excessive tensions in the cables that connected the sEMG sensors to the microcontroller. A first-tentative forearm bracelet for the sEMG collection has been designed to solve this problem (Fig. 1) by integrating a microcontroller, two sEMG sensors, a Bluetooth module, a single-cell 500 mAh Li-ion battery, a 3D-printed case, and a Velcro band.

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B. Ergonomics

The previous device was placed in position, over the hand, using Velcro bands. The high elasticity of both such a fastening system, however, made the exoskeleton produce different trajectories from those it was designed for since each displacement modified the kinematic coupling. An anatomical wrist splint has been introduced to provide a sufficient rigid interface base with the hand, wrist, forearm.

A three-dimensional CAD model has been created by exploiting a measuring arm equipped with a 3D laser scanner to add housing for the fingers modules and a slide for anchoring the motor box. Finally, a 3D-printed version of the modified splint has been produced (Fig. 2).

C. Mechatronic architecture

Now the case incorporates not only all the electronics but also the batteries. The power supply stage, consisting of two rechargeable 3.7 V lithium-ion batteries connected in series with a capacity of 2600 mAh each, has been designed to last up to eight hours depending on the usage.

Thirdly, the actuation system has had to undergo significant changes. While in the previous prototype the motor unwound and wrapped the actuation cable around a pulley integral with its shaft, in the new actuating system, the motor sets in motion a secondary shaft through a toothed belt drive. Four pulleys of different diameters are mounted on this shaft and distributed along its length. As in the previous version, this adjustment allows obtaining the same angular velocity for all the fingers.

III. DISCUSSION AND CONCLUSIONS

The strengths and weaknesses of the new exoskeleton prototype — resulting from the changes set out in the previous section — will now be discussed. Direct reference will be made to each of the subsections presented above.

sEMG technology (Subsec. II-A) — The sEMG bracelet has not only proved to be a valid solution for decoupling the acquisition system from the wrist movements, but it has also proved to be an excellent tool as it reduces the number of cables, and allows simple streaming of sEMG data to any external platform for development and monitoring purposes.

Ergonomics (Subsec. II-B) — The ergonomics of the device has increased, and the stability of the exoskeleton-hand kinematic coupling has significantly been improved. The use of a splint also allows a better distribution of effort on the surface of the forearm. There are still aspects that can be improved, such as increasing breathability and using a variable stiffness structure to provide better fit where required.

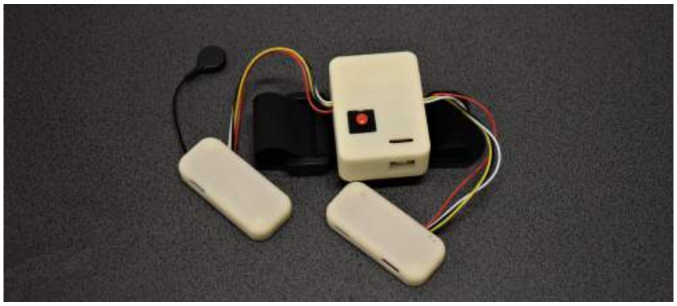

Fig. 1. The developed sEMG bracelet.

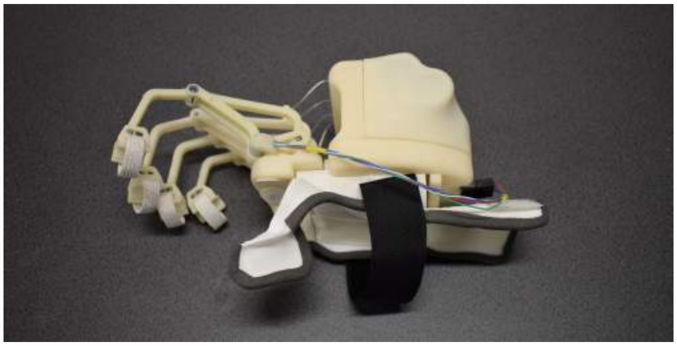

Fig. 2. The new HES architecture mounted on the newly-introduced splint.

Mechatronic architecture (Subsec. II-C) — The more significant innovation of this new architecture is undoubtedly owed to this aspect: the whole system is now standalone and entirely wearable. If on one side, this means a worse disposition of the masses, which are now concentrated on the hand, on the other side, it also allows for the complete elimination of visible power and signals wiring, making the system less bulky and electrically safer. Two other important strengths are the improvement of the efficiency of the motion transmission (thanks to the toothed belt), and the possibility to quickly replace exhausted batteries with a couple of loaded spares (thanks to the modular structure of the case).

The new architecture of the HES here described (see Fig. 2) is certainly interesting as it presents innovative and noteworthy aspects compared to the current state of the art of wearable robotics for hand disabilities. The complete wearability and freedom from external equipment make it a remarkable solution; the tailor-made device ergonomics and kinematics, both customized on the anatomy of the user, enrich its value.

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