The Powered Exoskeleton introduction in Tele Rehabilitation: from the dream to the reality

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Abstract—

Depending on the level and completeness of the damage, the bone marrow injury can give rise to four different clinical frameworks: tetraplegia, paraplegia, tetraparesis, paraparesis. The impact of the problem for the health care system is very high and complex for the risk of death and for the costs. It is widely demonstrated that solutions for rehabilitation and for the aids which allow the "upright position" are also very useful to improve the functionality of the internal organs and avoid the bedsores. The state of art of the Powered Exoskeletons and usability in the rehabilitation process have been investigated. Particular attention was also dedicated to the novel methodologies based on the Brain Computer Interface (BCI) applied to the Powered Exoskeletons. The study ends pointing out the basic issues for the integration to a health care process; (a) the integration with the domotics, tele-rehabilitation, virtual reality environments; (b) the importance of a wider risk analysis.

***Keywords*—Powered exoskeleton, tele-rehabilitation**

I. Introduction

THE medullar damage is a very wide ranging health problem.

Depending on the magnitude of the damage to the spinal cord, medullar lesions occur distinguish themselves in complete and incomplete [1-3]: the complete lesion is where it exists a total anatomic interruption of all nerve communication below the level of wound; the incomplete lesion, on the other hand, presuppose a kind of neurological "savings" below the level of injury. Depending on the level and completeness of the damage, the injury bone marrow can give rise to four different clinical problems [3]:

- *Tetraplegia*
- *Paraplegia*
- *Tetraparesis*
- *Paraparesis*

The dimension of the problem is very wide.
It has been reported in [3] that:

- The ratio is about 1 every 1000 subjects in the USA.
- The ratio is 18/20 new cases every 1.000.0000 subjects for each year; the 80 % of subjects has an age comprised between 10-40 years with a prevalence of the paraplegia.
- The 67.5 % of cases are traumatic.

The rehabilitation and the design of specific aids are a key point for these subjects: there is in fact the need to make all efforts to help them to recover the mobility and autonomy in the better possible manner. It is widely demonstrated that solutions for rehabilitation and for the aids which allow the "upright position" are also very useful to improve the functionality of the internal organs and avoid the bedsores. However such solutions are encumbering, cost-expensive and cannot thus be used at home in tele-rehabilitation but can be used only in specialized clinics.

II. The Introduction of the Powered Exoskeleton

A. *The mechanical exoskeleton versus the wheelchair*

The Mechanical (not motorized) Exoskeleton, such as the Reciprocating Gait Orthosis (RGO), even if, allows a rehabilitation with a "upright position" needs a high energy consumption during the use ; for this reason subjects prefer to use the wheelchair at home, a useful aid but an incomplete rehabilitation-tool that does not allow the "upright position" and the assisted deambulation [4].

For this reason since the 1800 the dream was to automatize the exoskeleton.

B. *The powered exoskeleton*

The introduction of the mechatronics and robotics is allowing new chances to the exoskeleton. Today we prefer to talk about the "powered exoskeleton" (PE) (also known as powered armor, power armor, exoframe, hardsuit, or exosuit).

The PE is a wearable system that includes electric motors, pneumatics, levers, hydraulics, or other technologies, integrated together that allow the automatic movement of the limb with increased strength, force and resolution.

Today these systems are employed in several fields, which are principally: (a) the medical field (as a device for rehabilitation); (b) the field of the defence and of the emergency (as a device allowing the force augmentation during the actions) and (c) the civil field (as a device allowing the augmentation of the force during the handling of the loads).

In some cases a PE can be useful in the different above listed fields.

It is evident that the PE could give a great contribution in tele-rehabilitation at home thanks the functionalities allowing:

- The assisted walk and the recovery of the motion control thanks to the programs for tele-rehabilitation conducted by means of the PEs also called in this case "Step Rehabilitation Robots".
- Improving quality of life, reducing the visit to the clinic.
- Minimization of costs, thanks to the reduction of therapists and the use the tele-rehabilitation.

It is possible to find in [5] a recent overview of commercial

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PEs capable to: help people with disabilities to regain control over their limbs, provide increased mobility to the elderly or augment capabilities of workers performing heavy labor. Two recent articles faced both [6] the usefulness and efficacy evidence and [7] the clinical effectiveness and safety. A core issue is the driving of the PE. Several solutions have been proposed, for example based on "special joy-stiks"; or on sensors which detect the forward inclination with the aid of crutches; or on EMG sensors..

C. The BCI and the powered exoskeleton

An innovative PE is the MindWalker system (designed and developed during an European Project by the MindWalker Consortium) as it comprehends BCI techniques in the driving control (https://mindwalker-project.eu/).

The objective of the project was to conceive a system empowering lower limbs in disabled people. The project main objective was to combine three expertise to develop the integrated MINDWALKER system:

- BCI technologies
- Virtual Reality
- Exoskeleton Structure and Control.

As reported in [8] the approach in the design of MindWalker comprehended the following key issues:

• The design of new smart dry EEG bio-sensors applied to enable lightweight wearable EEG caps for everyday use.

• Novel approaches to non-invasive BCI in order to control a purpose-designed lower limbs orthosis enabling different types of gait. Complementary research on EMG processing to strengthen the approach.

• The design of A Virtual Reality (VR) training environment assisting the patients in generating the correct brain control signals and in properly using the orthosis, comprising both a set of components for the progressive patient training in a safe and controlled medical environment, and a lightweight portable set using immersive VR solutions for self-training at home.

• The design of an orthosis to support the weight of an adult, to address the dynamic stability of a body-exoskeleton combined system, *and to enable* different walking modalities

III. FUTURE DIRECTIONS

This work points out the new opportunities of the PEs for rehabilitation of subjects with medullar damages. These PEs are moving also towards the integration of BCI techniques and are showing promising perspectives in health care with the integration with Tele-Rehabilitation care. The PEs can be bought or rented and used at home. It is thus foreseeable the increasing of the design of a process of integration with the health care system.

This process should consider the following technological issues:

• Design/Integration to the domotic environment at home.

• Integration to the Tele-Rehabilitation Environment [8] to periodically communicate the performances and interact with actors of the health care system.

• Integration of the Virtual Reality [9] and Augmented Reality to improve the care also at home.

• A careful risk analysis not only for the system which is a Medical Device, but also dedicated to the environment (home, work) of use with a careful consideration to the involved fields (Figure 1). An example of the importance of the risk analysis for the PEs can be found in [10] where it is described the activity of risk analysis around the PE MindWalker suggesting applications and extensions.

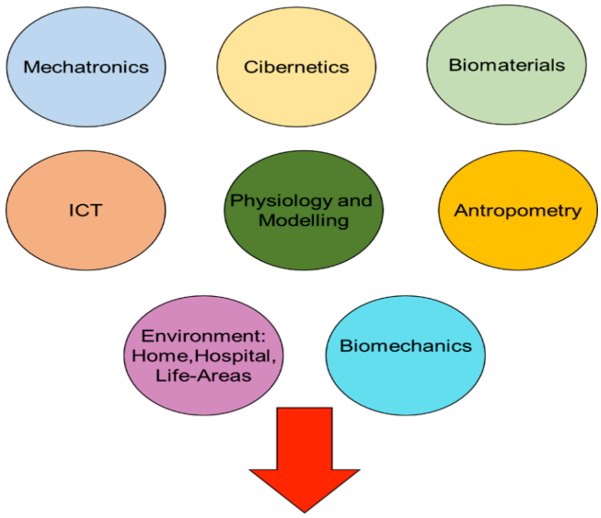

Figure 1 Fields involved in the design & integration in Tele-rehabilitation

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