SS3- Wearable Rehabilitation Robotics

Development of a Exoskeleton for Lower Limb Rehabilitation*

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Abstract. Every year, stroke leaves many disabled people who need rehabilitation to recover lost movements and return to a normal live. Exoskeletons are becoming a very powerful tool to help clinicians improve this rehabilitation process. This paper presents a robotic platform aimed to assist overground gait training for disabled people. It's a six degree of freedom device and has been designed for different control strategies. A first trial with a healthy subject showed that it can replicate a normal gait pattern for walk assistance. Further investigation will evaluate the device with stroke patients in rehabilitation and make a comparison between different robotic therapies.

1 Introduction

Stroke is loss of brain function due to disturbance in blood supply on the brain. When this occurs, the person that survives, in general, has one or more limbs paralyzed in one side of body because the affected area of brain cannot function [1]. The recovery process of regain lost movements is more effective in the first 3 to 6 months after stroke onset and it is high dependent on the individual [2]. By this time, physiotherapists help the patients to work on the ability to produce strong movements and perform tasks using normal patterns. The most important tasks to be relearned are those related to activities of everyday living. For lower limb, the possibility to walk again is the most important task claimed by patients suffering from stroke, in order to return to a normal life as possible [3].

In order to improves the rehabilitation of stroke, in the last years many robotics platforms has been developed, such as wheelchairs, protheses and exoskeletons [4], the latter being wearable robots attached to subjects limbs in order to replace or reinforce their movements. This paper presents a lower limb exoskeleton developed to assist gait training in therapeutic programs.

* This work has been developed thanks to HYPER project *(Hybrid Neuroprosthetic and Neurorobotic Devices for Functional Compensation and Rehabilitation of Motor Disorders)*. Ministerio de Ciencia y Innovación, Spain. (CSD2009 - 00067 CONSOLIDER INGENIO 2010).

J.L. Pons et al. (Eds.): *Converging Clinical & Engi. Research on NR*, BIOSYSROB 1, pp. 87–91.
DOI: 10.1007/978-3-642-34546-3_14

2 Robotic Platform

The developed exoskeleton is a lightweight wearable device (about 10 kg) with six degree of freedom, with hip, knee and ankle been powered joints. The degree of assistance delivered by it can be adjusted for each specific patient, since every joint is independently controlled. It's adjustable to fit different patient's parameters in order to allow an optimal fitting in people between 1.5 to 1.9 m. Aluminum and stainless steel are used in the mechanical structure in consideration of mechanical strength and lightness. The knee hinge function was performed by a four-bar mechanism, as described in [5].

2.1 Actuators

The design and selection of exoskeleton actuators was based on characteristics identification of torque and power of each joint during no pathologic gait at normal speed [6]. The actuators technology should have high power density allowing the implementation of lightweight solution for wearable devices. A study of different possible candidate was evaluated and DC motors plus a gearbox type harmonic drive was selected.

In the work of Colombo et al [7] an average of 35 Nm of torque for hip is presumed to be suitable enough for most patients. Based on that, a DC motor with 390 mNm of torque and a gearbox of 100:1 ratio was selected for hip, giving it a final torque of 39 Nm. For knee and ankle, a motor with 130 mNm of torque capability and a gearbox of 160:1 ratio give these joints 20.8 Nm of torque.

2.2 Sensors

The exoskeleton is aimed to allow therapeutic gait rehabilitation strategies. To achieve this it is equipped with kinematic (angular position, velocity and acceleration) and kinetic (interaction force between limb and exoskeleton) sensors.

Each joint is equipped with a precision potentiometer used as an angular position sensor. Strain gauges attached at each linkage are used as torque sensor. The exoskeleton footplate is equipped with two force sensors in order to detect distinct phases of gait cycles. A custom made IMU (*inertial measurement unit*) is attached to patient's chest to capture trunk's inclination. Fig. 1 shows the exoskeleton, its actuators and sensors.

2.3 Control Architecture

The control architecture consists in three main hardware parts: a smartphone that runs a user interface, a dedicated computer standard PC104 that runs the low level control and the electronics servo drivers that drive the brushless DC motors.

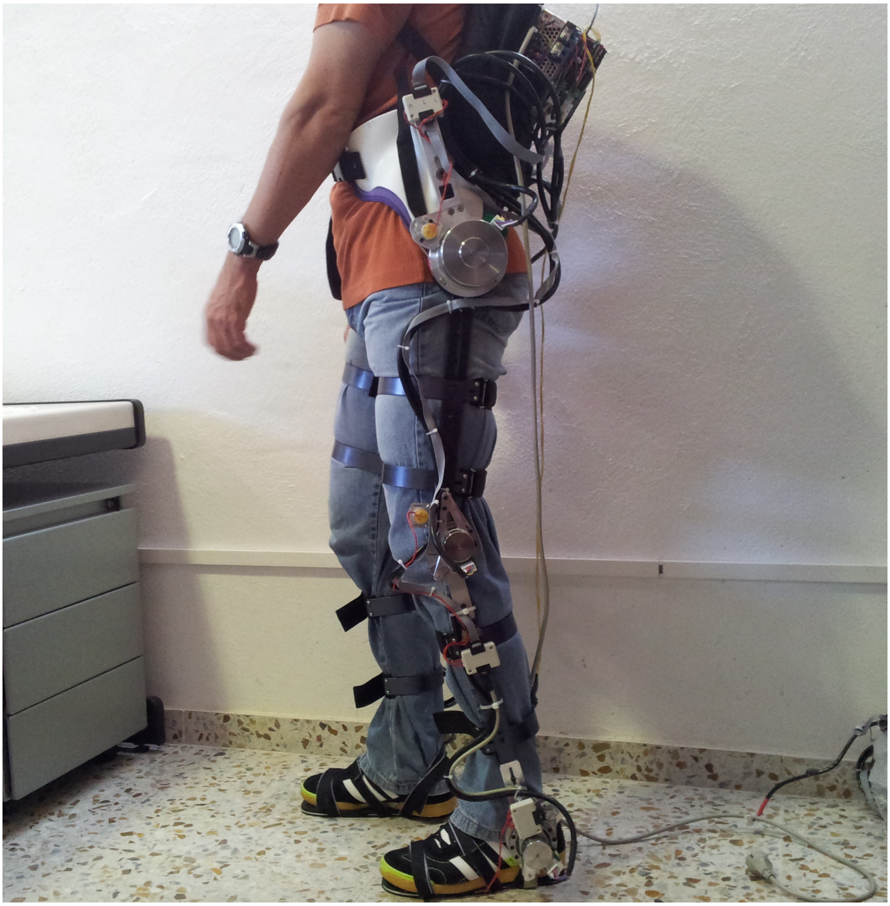

Fig. 1 Healthy subject using the lower limb exoskeleton

The user's interface allows therapists start/stop therapy execution, change the gait speed and commute between control modes. It communicates wirelessly by Bluetooth technology. The low level control adjusts the gait pattern accordingly to the speed and control mode selected by therapists. All control's algorithms are implemented using *Simulink* under the *xPC Target* software for real time control.

3 Results

In order to implement different robotic therapies, three control's algorithm were developed: Trajectory, Impedance and Torque Control. Trajectory control is the widely implemented robotic training strategy [8]. In this control mode the patient's limb is guided to a fixed reference gait trajectory previous recorded from a healthy subject.

Impedance control allows the mechanical impedance between the subject's limb and the exoskeleton to be controlled. It can be thought as an improvement of trajectory control and the idea behind it is to guide the patient's limb to a reference trajectory allowing a variable deviation from reference. Finally, Torque control mode is especially interesting for repetitive tasks with controlled limb torque, like an ankle mobilization.

A first trial was performed with a healthy subject using the exoskeleton commanded by trajectory control strategy. The trajectories executed by the exoskeleton for hip, knee and ankle can be seen in Fig. 2.

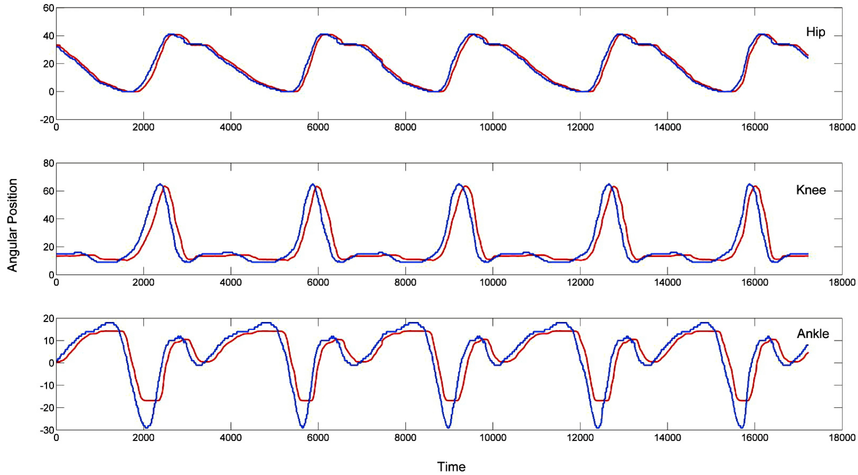

Fig. 2 Trajectories performed by the exoskeleton: in blue reference trajectories; in red performed trajectories

4 Discussion

In gait rehabilitation exoskeletons assume the role of moving the patient's leg in a normal gait pattern, applying the necessary force to complete the subject's movement on impaired limb. These wearable robots are capable to delivery training with high intensity and accuracy for doing repetitive tasks, which make them a valuable assistant tool to provide high quality treatment, not replacing therapist, but supporting the therapy program and also been used at patient's home [9].

To achieve better results in rehabilitation robotics, is important to choose the most effective therapeutic strategy. Different robotic gait therapies, such as assist-as-needed, challenge-based, etc., has been used in the past years, but which one is more effective is not yet clear [10]. Trying to clarify that, further investigation with the developed device will compare different gait therapies in a randomize trial.

5 Conclusion

The exoskeleton presented is aimed to be a powerful assistant for overground gait training. Because the gait movement provided by it should be as similar as possible to normal human gait, it is equipped with kinematic and kinetic sensors and controlled by distinct algorithms. These algorithms bring the possibility to implement different gait therapies, that in a future work will be compared to identify which one is more effective, since in the literature there is an absence of direct empirical comparison between robotic assisted gait therapies.

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