Control of an active pelvis orthosis for gait assistance in the elderly

A. Parri[1], T. Yan[1], N. d'Elia[1], F. Vannetti[2], G. Pasquini[2], F. Giovacchini[1], M. Fantozzi[1], M. Cortese[1], R. Molino Lova[2] and N. Vitiello[1,2]

[1] *The BioRobotics Institute, Scuola Superiore Sant'Anna, viale Rinaldo Piaggio 34, 56025, Pontedera (PI), Italy.*
[2] *Don Carlo Gnocchi Foundation, via di Scandicci 256, 50143, Firenze, Italy.*

***Abstract* — Gait impairment is a common consequence with people getting old, bringing a great inconvenience for their daily life. In this paper, a light-weight active pelvis orthosis is used to provide assistance to improve the mobility of the elderly. An adaptive oscillator based control strategy is proposed to predict the next status of a hip joint angle. Then the desired assistive torque is estimated by multiplying the predicted and current angle difference by a virtual stiffness. This control strategy is evaluated with an elder subject walking on the treadmill wearing the orthosis. Experiment results showed usability of the device for elderly gait assistance. Under transparent mode utilization, the orthosis does not hinder intentional movement of the wearer while, under assistive mode utilization, it is capable to provide user with a suitable assistive torque.**

***Keywords*—Adaptive oscillator, active pelvis orthosis, gait assistance, elder people.**

I. INTRODUCTION

It is estimated that in 40 years from now, population over 60 will present 35% of all the population in Europe, bringing greater pressure on the economy and society [1]. Numerous population based studies have reported a 35% and 80% prevalence of gait disorders among people over 70 and 85 separately. Gait impairments lead to several major consequences causing mobility and independence limitations due to immobility (cardiovascular diseases, cognitive decline, etc.) which can either be fatal or reduce people quality of life [2].

In the last two decades, wearable orthoses have been developed with the target of augmenting the load capability or assisting locomotion [3]. In this paper, a light-weight active pelvis orthosis (APO) presented in [4] and preliminary tested in [5] with an healthy subject (Fig. 1), is used to provide gait assistance based on an adaptive oscillator controller. An orthosis (also named exoskeleton) for gait assistance is a portable mechanical device that is anthropomorphic in nature, is "worn" by the user, and fits closely to its or her body. The state-of-the-art includes several exoskeletons which differ from each others for the number of joints actuated (full body, lower limb, hip, etc.), type of use (assistance, rehabilitation, human augmentation), mechatronic design (mechanics, actuation system, control strategies), and human-robot interface [3].

Recently, among the control strategy for assistive orthoses, oscillator based control is used more frequently because of its good synchronization property. Experimental results from users wearing a treadmill-based lower limb exoskeleton and an active elbow exoskeleton, respectively LOPES and NEUROEXOs, proved the efficacy of an adaptive oscillator (AFO) based assistive strategy [6], [7].

In this paper we briefly describe the mechatronic system of APO, hence providing a description of the control algorithm (section II), and we report results from a preliminary experimental session with an elder subject to assess the usability of APO in a gait assisting scenario in section III. Section IV draws the conclusions.

II. METHODS

A. APO mechanics

The light weight APO (4.2 kg) is constituted of a C-shaped carbon fibre frame enveloping the trunk and two carbon fibre links interfaced distally with thighs and coupled to the actuation units endowed on the frame. A comfortable physical human-robot interface is ensured by five orthotic shells coupled with user trunk and thighs designed with a large interaction surface to reduce pressure on the wearer. Several regulation degrees of freedom (DoF) allow to fit a wide range of user dimensions. The device was designed with an active hip flexion-extension DoF with a range of motion (RoM) that ranges from -20° to 110°. Furthermore, linkages endowed a passive DoF for abduction-adduction with a RoM from -15° to 25°. Two series elastic actuators (SEAs) [8] provide compliant actuation and minimum joint output impedance across the frequency spectrum of gait. Maximum assistive torque is set to 35 N·m.

B. APO control system

The control system is characterized by a hierarchical structure: a low-level velocity control, on top of which a closed-loop 2-pole-2-zero control is used to control the joint torque and a high-level layer implementing an adaptive assistance strategy. The torque is estimated by measuring the deformation of the SEA spring by means of two encoders.

The high-level strategy aims at providing a desired torque reference, namely τ_{des}, variable over the stride based on an algorithm recently presented in [6], in which AFO is depicted to estimate and predict the hip joint trajectory in real time, realizing a model free approach to provide walking assistance. This algorithm makes use of adaptive oscillators which (coupled to a properly designed non-linear filter) can track and provide a zero-delay estimate of a quasi-sinusoidal periodic signal. Hence, it is possible to learn phase φ, frequency and envelop of each hip joint angle and to reliably predict, thanks to a supervised learning model, the joint angle over the stride period by means of a phase-lead $\Delta\varphi$ settable by the experimenter (in our work $\Delta\varphi$ = 0.628 rad). The assistive reference torque is provided through:

$$\tau_{des} = K_v \cdot \left[\widehat{\theta}_J(\varphi + \Delta\varphi) - \widehat{\theta}_J(\varphi)\right] \quad (1)$$

where K_v [N·m/rad] is a tuneable virtual stiffness, $\widehat{\theta}_J(\varphi)$ and $\widehat{\theta}_J(\varphi + \Delta\varphi)$ are the hip joint angle estimate and its future value. In this way the user is gently assisted by attracting its hip angle to the future position during each moment of the gait cycle.

C. *Experiment*

In order to evaluate the feasibility of the APO system, a prototypical task of gait assistance was designed and tested on an elderly volunteer (male, 73 years old, 71 kg, 1,8 m). The experiment was carried out at the premises of Don Carlo Gnocchi Foundation (Florence, Italy). The elderly subject was requested to walk on a treadmill for about 6 minutes at 2.4 km/h under the transparent mode (TM), namely when $K_V = 0$, and assistive mode (AM), namely when $K_V \neq 0$; for the AM session the virtual stiffness was set at 20 N·m/rad. For both AM and TM modalities, we recorded the joint angle and SEA torque of the left and right legs. Collected data were segmented and resampled between 0 and 100% of the gait cycle. From the collected variables we derived the joint velocity and SEA power. It is worth noting that we assumed that the joint angle and velocity are positive when the hip is flexing.

III. Results

In this section, results of the experimental session are reported. Fig. 2 shows the average curves with the standard deviation contour of the collected/computed variables for the TM and AM sessions respectively. Under the TM, the value of the measured SEA torque is quite close to zero, and reaches a negative peak of about -1.4 N·m - 3% of the maximum flexion-extension torque powered by the hip muscles of a 75-kg elderly subject during a ground-level walking task at natural cadence [9] - in correspondence of the swing phase of both the right and left legs. As a consequence this is also the case in which the SEA power has a negative peak of about -1.5 W: this is the moment in which the APO is hindering more the movement of the user. The mean power is about null and reaches -0.54 ± 0.05 W.

Under the AM, while the walking pattern - in terms of range of motion, range of the joint velocity and shape of the angle profile over the gait cycle – does not differ from the TM session, data shown in Fig. 2 point out that: i) the assistive torque over one gait cycle oscillates between -6 N·m and 9 N·m; ii) the SEA power is mostly positive and the peak value – in correspondence of the middle-swing phase – is about 20 W. In order to quantitatively assess the actual transfer of mechanical power between the human and the exoskeleton, we computed the mean value of the SEA power for the AM session that is 3.41 ± 0.46 W over one stride cycle.

IV. Conclusion

In this paper, a light-weight APO actuated by SEA is exploited to evaluate its usability for elderly gait assistance; experiments with an elder volunteer wearing APO and walking on treadmill under TM and AM have been implemented. The kinetic and kinematic results proved that APO properly tracks the human walking pattern in real time. Under TM utilization the parasitic torque does not hinder the intentional movement of the subject requiring no additional effort. Finally, the device can effectively transfer mechanical power to the wearer under AM, demonstrated by a mean power of about 4 W over the gait cycle. In future works, metabolic consumption under TM and AM will be investigated to assess the APO efficacy in assisting gait of elderly. the user.

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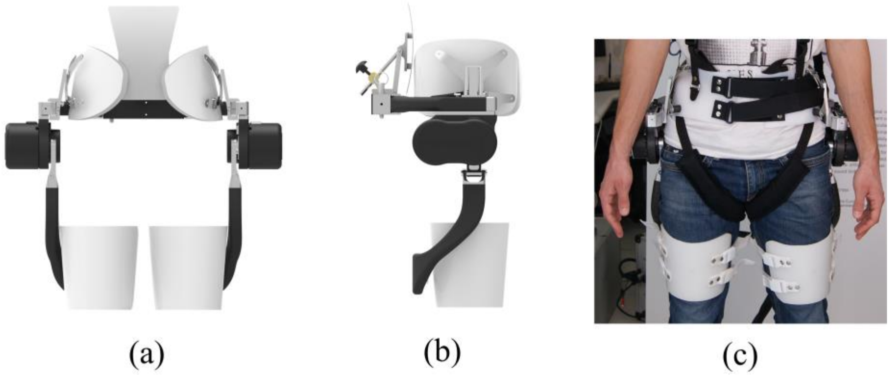

Fig. 1. Overview on APO. a) CAD frontal view. b) CAD lateral view. c) Frontal view of a subject wearing the device.

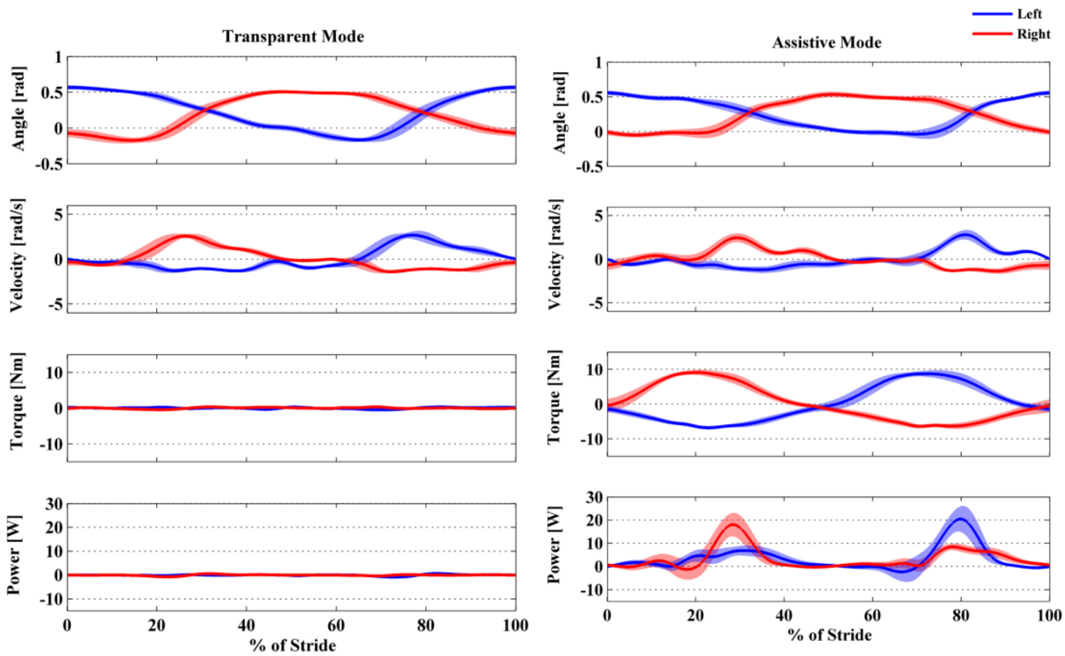

Fig. 2. Walking with the APO under TM and AM. For each gait speed, the following variables for left and right hip joints are averaged over all strides and plotted against the percentage of the stride cycle: hip joint angle, hip joint velocity, SEA torque and power. For each graph the average curve (solid line; blue for left and red for right joint) is shown along with the standard deviation contour.