Active and passive devices for tuning impedance in wearable robotics

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Active and Passive Devices for Tuning Impedance in Wearable Robotics

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Abstract:

Wearable robots, i.e. active orthoses, exoskeletons, and mechatronic prostheses, represent a class of biomechatronic systems posing severe constraints in terms of safety and controllability. Additionally, whenever the worn system is required to establish a well-tuned dynamic interaction with the human body, in order to exploit emerging dynamical behaviours, the possibility of having modular joints, able to produce a controllable viscoelastic behaviour, becomes crucial. Controllability is a central issue in wearable robotics applications, because it impacts robot safety and effectiveness. Under this regard, DC motors offer very good performances, provided that a proper mounting scheme is used in order to mimic the typical viscoelastici behaviour exhibited by biological systems, as required by the selected application. In this paper we report on the design of two compact devices for controlling the active and passive torques applied to the joint of a wearable robot for the lower limbs. The first device consists of a rotary Serial Elastic Actuator (SEA), incorporating a custom made torsion spring. The second device is a purely mechanical passive viscoelastici joint, functionally equivalent to a torsion spring mounted in parallel to a rotary viscous damper. The torsion stiffness and the damping coefficient can be easily tuned by acting on specific elements, thanks to the modular design of the device. The working principles and basic design choices regarding the overall architectures and the single components are presented and discussed.

I. INTRODUCTION

The classic paradigm "the stiffer is the better", well established in industrial domain [1] do not apply to the field of wearable robotics, where compliance and adaptability play a central role. The development of robots that can establish dynamic interactions with the human body requires the use of joints and actuators whose mechanical impedance can be finely adjusted (i.e. VIJ, Variable Impedance Joints and VIA, Variable Impedance Actuators). The tuning of the mechanical impedance allows to improve the dynamical performances of a joint, similarly to the variation of human joints stiffness, which is usefully exploited to perform different tasks [2].

The possibility of tuning the dynamical properties of the robotic systems is even more crucial in the design of Wearable Robots (WRs) in strict contact with the Human Body (HB) in order to give rise to useful emerging dynamical behaviours thanks to the symbiotic interaction between the WR and the HB. Furthermore, the presence of compliant elements allows an energy bouncing between WR and HB so to demand also lower WR actuation requirements. In this way the robot does not move rigidly the limbs of the subject through a prescribed pattern, but it offers assistance as needed (AAN) [3] or produces dynamical behaviours which aim to be very close to physiological movements. The proper implementation of such concepts leads to a safer pHRI (physical Human Robot Interaction), which is a necessary condition for robots intended to operate for assistive or rehabilitation purposes. Joints compliance can be either achieved by actively controlling a stiff actuator so to mimic elastic behaviour, or by employing passive elements.

The first example of a passive compliant actuator is the Series Elastic Actuator (SEA) [4] in which a spring is connected in series to a linear gear motor. This actuator architecture provides the possibility of storing energy (thus increasing efficiency), while improving safety, since shocks can be absorbed by the elastic element with a virtually zero delay time. The first linear SEA opened the way to the development of a number of rotary serial elastic actuators [5-10]. All the proposed approaches rely on the control for what concerns damping regulation.

In Sec. II we will present a newly developed compact rotary sea, while in Sec. III a passive viscoelastic joint is described.

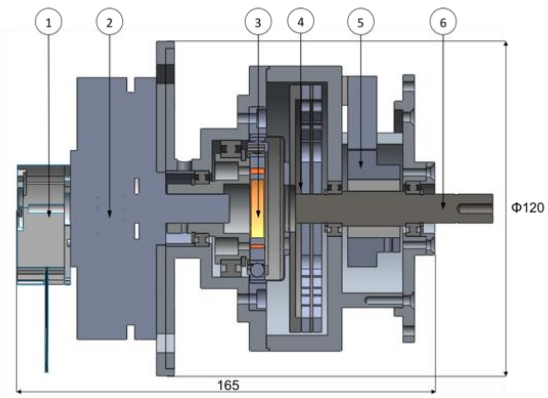
II. ROTARY SERIAL ELASTIC ACTUATOR

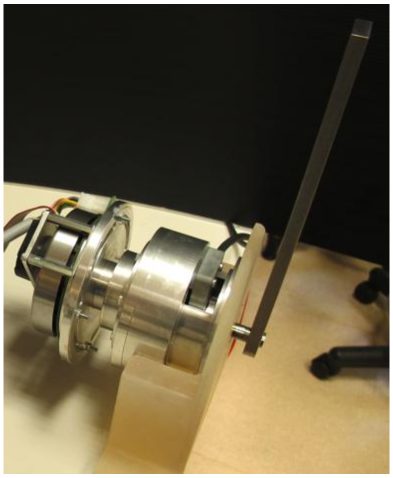
In Figure 1-a a cross section of the SEA proposed by the authors is depicted. The actuator is comprised of: EC 90W Maxon motor (Fig. 1-a, 2) connected to an incremental encoder Maxon HEDL Fig. 1-a, 1); a Harmonic Drive reduction gear 100:1 in standard configuration with the circular spline fixed to the chassis (Fig. 1-a, 3); two custom torsion springs arranged in parallel configuration. Each spring is fabricated in maraging steel alloy 300 and is able to withstand a maximum torque of 15 Nm with stiffness of 100 Nm/rad and maximum rotation of ± 0.15 rad (Fig.1-a, 4); an output magnetic incremental encoder ASM with 15 bits resolution (Fig. 1-a, 5); an output shaft (Fig. 1-a, 6).

The parallel configuration of the two torsion springs has been tested and characterized by a custom-made dynamometric test bed. The maximum output peak torque for the SEA is 30 N·m and the maximum peak velocity is 5.2 rad/s. In Figure 1-b a picture of the actual prototype is reported.

III. PASSIVE VISCOELASTIC JOINT

The passive viscoelastici joint is a purely mechanical system with interchangeable modular components, able to provide different torque-displacement and torque-velocity characteristics, adaptable to a wide range of operative conditions. The two sub-modules for the torsion spring and damper will be described in the next paragraphs, while a graphical overview is provided in fig. 3.





(a) (b)

Figure 1. SEA cross section (a) and prototype (b). Total dimensions: 165 mm x 120 mm; total weight: 2.0 kg.

III. A. Torsion stiffness

The torsion stiffness module is implemented using *n* linear compression springs connected between the joint shaft and *n* rollers sliding on cam profiles. This arrangement generates a centering elastic torque M(θ) against an external rotation of the joint shaft. A desired stiffness characteristic can be achieved opportunely selecting the shape of the cam.

In Figure 2-a a schematic representation of the stiffness module is depicted (only one spring k_m is represented). The analytical expression for the cam profile, $x(\theta)$, necessary to implement a generic torsion stiffness, $k_\theta(\theta)$, can be amenably evaluated from energetic considerations, provided that the diameter of the rolling element can be neglected if compared to the average radius of the cam profile:

$$x(\theta) = \sqrt{\frac{2}{nk_m}\int_0^\theta d\alpha \int_0^\theta k_\theta(\alpha)d\alpha}$$

Examples cam profiles for different $k_\theta(\theta)$is shown in Fig. 2-b.

III.B. Torsion damping

The torsion damping module is implemented connecting the joint shaft to a roller, which compresses a rubber tube filled with silicone oil, causing a laminar flow. The partial closure of a valve causes pressure drops impeding the fluid flow, thus producing a damping torque proportional to the angular speed of the input shaft.

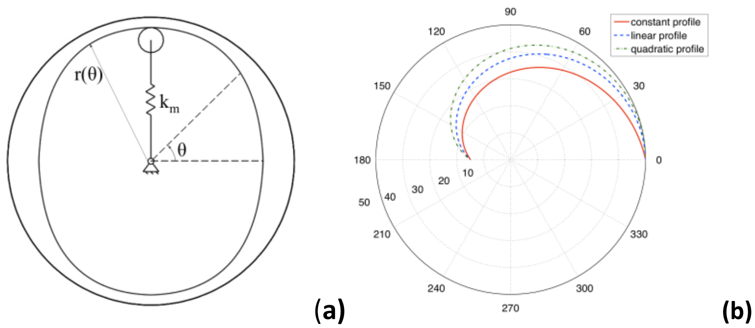


Figure 2. (a) Schematic representation of the torsion spring module: k_m is the spring stiffness, θ the shaft rotation and $r(\theta)$ the cam profile. Only one compression spring is depicted, for clarity sake.(b) Cam profile for constant (in red), linear (in blue) and quadratic (in green) torsion stiffness characteristic. Dimensions are in mm.

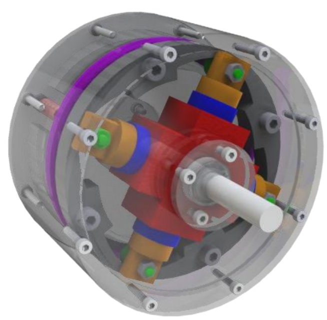


Figure 3. Overview of the rotary viscoelastic joint. The external frame is shown in transparency. OD 115 mm, axial width: 85 mm. Total mass: 1.4 kg.

IV. CONCLUSIONS AND FUTURE WORKS

In this paper Authors reported on their on-going work on active and passive tunable impedance joints for wearable robotics applications. What characterizes the presented devices is their modularity. For what concerns the SEA, 18 different configurations can be easily achieved without changing the frame and the mounting scheme, just replacing the motor, the harmonic drive and the elastic elements, whose number and type of connection (i.e. in series or in parallel) can be adapted to the desired physical stiffness. As it regards the passive viscoelastici joint, different torque-angle and torque-velocity characteristics can be easily obtained by changing the cam profile and by acting on the closure of the valve.

The presented devices allow to easily tune the dynamical properties of wearable robots. Such feature is particularly important whenever the WR has to establish a specific dynamical interaction with the human body, in order to produce useful emerging dynamical behaviours. Future work regards the integration of the proposed device into a wearable robot for gait assistance, currently under development at the Biomedical Robotics and Biomicrosystems Laboratory.

ACKNOWLEDGMENT

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REFERENCES

[1] K. Salisbury, B. Eberman, M. Levin, W. Townsend, "The Design and Control of an Experimental Whole-Arm Manipulator", International Symposium on Robotic Research, pp. 233-241, 1991.

[2] A. Bicchi and G. Tonietti, "Fast and Soft-Arm Tactics - Dealing with the Safety-Performance Tradeoff in Robot Arms Design and Control", IEEE Robotics & Automation Magazine, vol. 11(2), pp. 22–33, 2004.

[3] H. Vallery, J. Veneman, E. Van Asseldonk, R. Ekkelenkamp, M. Buss, H. Van der Kooij, "Compliant Actuation of Rehabilitation Robots", IEEE Robotics & Automation Magazine, vol. 15(3), pp. 60–69, 2008.

[4] G. A. Pratt, M. M. Williamson, "Series Elastic Acutators", Proceedings of the International Conference on Intelligent Robots and Systems, vol. 1, pp. 399-406, 1995.

[5] J. W. Sensinger, R. F. Weir, "User-Modulated Impedance Control of a Prosthetic elbow in Unconstrained, Perturbed Motion", IEEE Transactions on biomedical engineering, vol. 55, pp. 1043– 1055, 2008.

[6] N. G. Tsagarakis, M. Laffranchi, B. Vanderborght, D. G. Caldwell, "A compact soft actuator unit for small scale human friendly robots", IEEE International Conference on Robotics and Automation, Kobe, Japan, pp. 4356–4362, May 2009.

[7] G. Wyeth, "Demonstrating the safety and performance of a velocity sourced Series Elastic Actuator", IEEE International Conference on Robotics and Automation, Pasadena, CA, USA, pp. 3642-3647, May 2008.

[8] J. F. Veneman, R. Ekkelenkamp, R. Kruidhof, F. C.T. van der Helm and H. van der Kooij, “A Series Elastic- and Bowden-Cable-Based Actuation System for Use as Torque Actuator in Exoskeleton-Type Robots”, The international journal of robotics research, vol 25(3), pp. 261–281, 2006.

[9] A. H. A. Stienen, E. E. G. Hekman, H. ter Braak, A. M. M. Aalsma, F. C. T. van der Helm, H. van der Kooij, “Design of a Rotational Hydroelastic Actuator for a Powered Exoskeleton for Upper Limb Rehabilitation”, IEEE Transactions on biomedical engineering, vol. 57(3), pp. 728-735, 2010.

[10] C. Lagoda, A. H. A. Stienen, E. E. G. Hekman, H. van der Kooij, “Design of an electric Series Elastic Actuated Joint for robotic gait rehabilitation training”, IEEE International Conference on Biomedical Robotics and Biomechatronics, Tokyo, Japan, pp. 21-26, September 2010.