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DEVELOPMENT OF AN EXOSKELETON FOR REHABILITATION OF LOWER LIMBS MOVEMENTS

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1 INTRODUCTION

This paper presents the development and construction of an impedance controlled exoskeleton for rehabilitation of lower limbs movements. The proposed device is named Exo-Kanguera (from Tupi, a Brazilian Indian language, *kanguera* means bones). It can be used to help people who suffered stroke or spinal cord injuries to recover their walking abilities. The impedance controlled characteristic is provided by using series elastic actuators. Three different designs of such devices are presented. The first one is the classical linear actuator originally proposed in Robinson et al. (1999), positioned at the hip joint. The second one, actuating at the ankle joint, is a compact version of it. The third one has a torsional elastic element and reproduces the knee movements. Experimental results of force and impedance control are presented for these series elastic actuators. Also, experimental results of the exoskeleton Exo-Kanguera performing a position tracking control are presented.

2 EXO-KANGUERA

The exoskeleton Exo-Kanguera has its main structure based on a Reciprocating Gait Orthosis LSU (Lousiana State University), although the reciprocating mechanism is not used. At this moment, it is only possible to test the exoskeleton wearing it on the right leg, improvements are being made to allow the use of the Exo-Kanguera on both legs. Figure 1 shows the final configuration of the Exo-Kanguera. The hip joint is driven by a linear series elastic actuator, constructed with the same characteristics of the actuator presented in Robinson et al. (1999). The ankle joint is driven by a compact series elastic actuator, designed and built in our laboratory with a weight and size reducing criterion. The actuator of the knee was also designed and built by the authors, with a torsional elastic element.

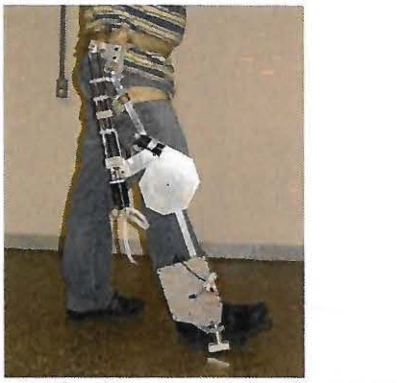

Figure 1: User performing a step with the Exo-Kanguera.

3 SERIES ELASTIC ACTUATORS

The impedance controlled characteristic of the Exo-Kanguera is achieved by using series elastic actuators at the joints. In this kind of actuator, an elastic element is added between the motor output and the actuator's end-effector. Besides the impact absorption characteristic provided by the spring, it is possible to measure its deflection and, therefore, the force applied at the actuator's end-effector. With this measure, force and impedance controllers are implemented to simulated human joint behaviors. In the next sections, experimental results obtained from the SEAs of the Exo-Kanguera when implementing force and impedance controllers are presented.

3.1 Linear Series Elastic Actuator

This section briefly describes the actuator used to drive the hip joint of the exoskeleton. The Linear Series Elastic Actuator (SEA) was reproduced according to the device developed by Robinson et al. (1999). The SEA is shown in Figure 2. The elastic series is composed by four linear springs (two for each actuation direction) with total stiffness equal, approximately, to 78.9 N/mm in each direction (Jardim and Siqueira, 2013).

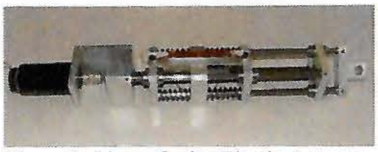

Figure 2: Linear Series Elastic Actuator.

To test the ability of the SEA to simulate the behavior of a given impedance, an experiment was considered with the actuator performing a spring-damper behavior, according to the impedance control strategy proposed in Pratt et al. (2004). The values of the stiffness (Kv = 10 N/mm) and damping (B_v = 10 Ns/mm) are used to compute the desired position for the motor and send it to the controller. The actual force value is computed considering the voltage measured through the potentiometer. For this experiment, an oscillatory force was applied in the ankle joint by the user. The results, applied forces and joint positions, for this behavior can be seen in Figure 3. Note that, as expected, the spring-damper combination recovers with exponential decrement after load force is removed.

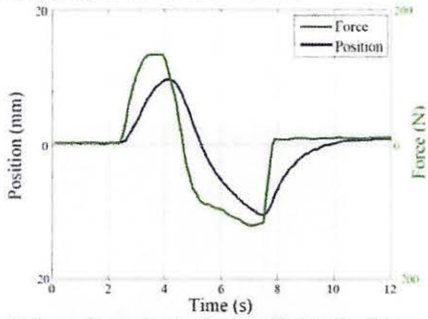

Figure 3: Impedance controller applied to the Linear SEA, spring-damper behavior.

3.2 Compact Series Elastic Actuator

This section presents the Compact Series Elastic Actuator (CSEA). It is used to drive the ankle joint. The aim in designing this actuator is to reduce its weight and size with relation the to previous one. Basically, smaller ball screw and nut set and springs are used. Also, the guides and motion platforms are grouped in only one element and the transmission is performed by a toothed belt with 2:1 reduction. Figure 4 show the final configuration of the compact series elastic actuator.

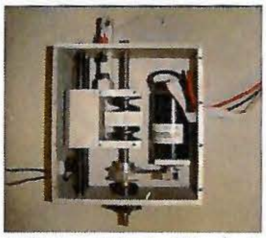

Figure 4: Compact Series Elastic Actuator.

The first controller implemented in the CSEA is a PID force control. The CSEA was positioned in a support and its end-effector was locked, so that the nut motion results in spring deflection, without output motion. Figure 5 shows the result obtained using the following values for the PID gains: Kp = 0,3, Kv = 0,03, and Ki = 0,2. The reference trajectory is a senoidal waveform with amplitude 60N and frequency 1 Hz. The graph shows that the applied force tracks the desired trajectory with a small phase delay.

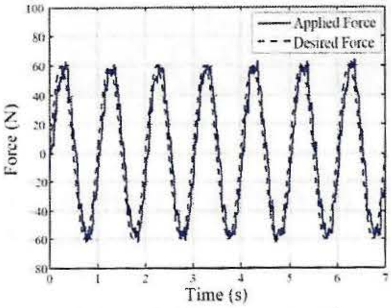

Figure 5. Applied and desired forces, senoidal waveform.

3.3 Torsional Series Elastic Actuator

This section shows the mechanical design of the Torsional Series Elastic Actuator (TSEA). The goal here is to develop an actuator able to reproduce the human knee behavior, satisfying features such as range of motion, torque and rapid response to impacts.

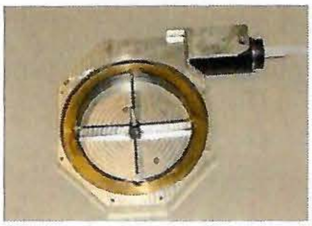

Figure 6. Torsional Series Elastic Actuator.

The proposed format of the elastic element is show in Figure 6. The external circumference (orange) represents a gear coupled to the motor through a pinion. The torque is transmitted to the output shaft (at the center) by four thin bars that represent the elastic element of the actuator. These bars were carefully designed to meet the specifications of the actuator, including the material selection.

4 CONCLUSIONS

This paper deals with the development of the Exo-Kanguera, an exoskeleton for walking rehabilitation. The proposed robotic device is driven by a set of series elastic actuators, acting in the hip, knee and ankle joints in the sagittal plane. The first experimental results show that the Exo-Kanguera can be used to evaluate impedance-based control strategies and rehabilitation protocols for recovering walking abilities.

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