IUTAM Symposium on Intelligent Multibody Systems – Dynamics, Control, Simulation
September 11 – 15, 2017, Sozopol, Bulgaria

Strain measurements in active orthoses for multibody model validation and control robustness improvement

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Abstract

The authors have developed a prototype of active knee-ankle-foot orthosis (fig. 1a) as an assistive device for the gait of spinal cord injured (SCI) subjects [1]. The prototype features a brushless DC motor at knee level to provide knee motion during the swing phase and an inertial sensor at shank level to detect motion intention and trigger the swing cycle.

On the other hand, the authors have also developed a computational multibody model of a subject wearing the mentioned active orthoses (fig. 1b), in which legs and orthotic devices have been modeled as independent entities, so that relative motion and interaction forces between leg and orthosis can be estimated when running a forward dynamic simulation of the model that relies on a CTC control scheme to track the subject's captured motion [2].

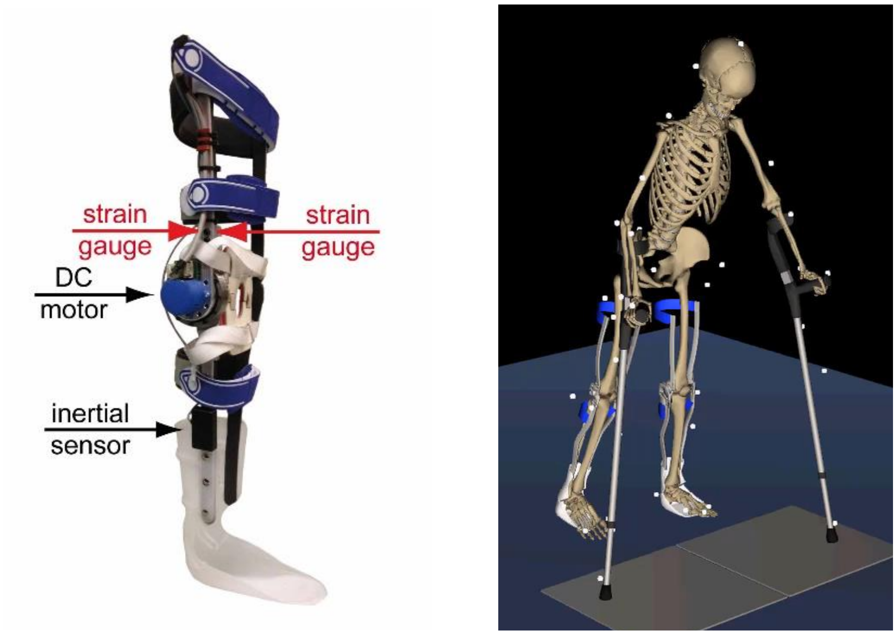

Figure 1: a) Active orthosis; b) Multibody model of SCI subject with orthoses.

In this work, the advantages of adding a couple of strain gauges in the front and rear faces of the external upright of each orthosis at thigh level, just above the DC motor (fig. 1a), are investigated with the two following objectives: i) validation of the leg-orthosis contact forces provided by the multibody model; ii) improvement in the robustness of the motor controller.

Figure 2a illustrates the modeling of leg and orthosis in the multibody model, along with the contact spring-damper elements at hip and knee levels. Figure 2b shows the interaction forces at hip level (right leg) obtained from the forward dynamic simulation for three different values of the parameters (stiffness and damping) of the contact elements. The blue and pink areas in fig. 2b correspond to the swing phase of the right and left leg, respectively.

The strain gauges will capture the strain due to axial stresses caused by the bending effects of the forces acting on the orthosis above the location of the gauges. Such forces are the leg-orthosis contact force at hip level and the weight and inertia forces of the top link of the orthosis. Therefore, it can serve to calibrate the parameters of the contact spring-damper elements and to assess the correlation between measurements and calculations.

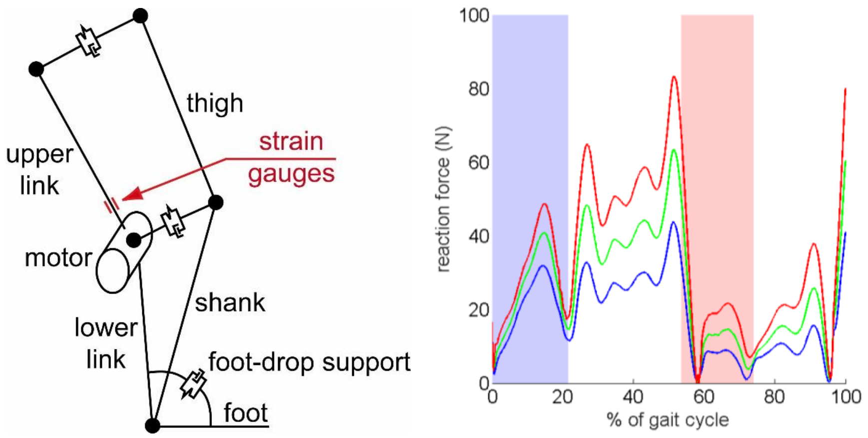

Figure 2: a) Leg-orthosis multibody model; b) Leg-orthosis contact force at hip level.

The control algorithm that launches the swing cycle of the orthosis is based on the angular velocity and linear acceleration data provided by the inertial sensors of both legs. To have the maximum time to complete the cycle before the leg touches down again, the swing cycle must be launched as soon as the motion intention of the leg is detected, but false positives cannot be allowed, which implies that some thresholds must be respected to avoid fall risk.

The strain gauges will detect the increment in load suffered by the orthosis when the corresponding leg is in stance phase, as the knee folds under the subject's weight and the leg presses against the orthosis, thus serving as a reliable condition of stance and enabling to relax the mentioned thresholds so that the swing cycle can be launched sooner.

References

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[2] Mouzo, F.; Lugris, U.; Cuadrado, J.; Font-Llagunes, J.M.; Alonso, F.J.: Evaluation of Motion/Force Transmission between Passive/Active Orthosis and Subject through Forward Dynamic Analysis. In J. Ibañez et al. (Eds.) Converging Clinical and Engineering Research on Neurorehabilitation II, pp. 815-819, Springer 2016.