Variable Stiffness Actuator Based on Infinitely Variable Transmission: Application to an Active Ankle Prosthesis

Christophe Everarts, Bruno Dehez and Renaud Ronsse

Abstract—Series elastic actuators are very popular in rehabilitation robotics. Among other advantages, elastic elements between the actuator and the load permit to store and release energy during the task completion. To comply with different gaits and cadences, it is necessary to modify the stiffness and thus to design Variable Stiffness Actuators (VSA). This contribution proposes to apply a particular concept of VSA to an active ankle prosthesis. We establish that a promising approach is simply to control the amount of energy stored in the elastic element. This contribution surveys a paper recently accepted to the IROS conference 2012 [1].

I. INTRODUCTION

Walking is a complex task, involving many energy exchanges across the body joints and segments, and with the environment. A non-trivial energy flow occurs during the stance phase (foot in contact with the ground). During the load acceptance phase, the ankle dissipates energy and during the second part of the stance phase, some energy is produced to achieve body propulsion. The production is larger than the dissipation, such that the net work of the ankle during self-paced walking is positive.

To optimally exploit the necessity to first dissipate then produce energy, the most advanced active ankle prostheses rely on the concept of Series Elastic Actuators (SEA) [2]. An intrinsic limitation of the SEA is that the mechanical stiffness of the compliant element can be optimized only for a single task and/or user. Consequently, people developed in the last few years the concept of Variable Stiffness Actuators.

II. VARIABLE STIFFNESS ACTUATORS WITH IVT

Recently, Stramigioli et al. [3] proposed a concept to implement a VSA illustrated in Figure 1.

![VSA model with IVT](Fig. 1. VSA model with IVT)

It consists of a motor connected in series with a torsional spring. This spring is connected to the effector via an Infinitely Variable Transmission (IVT), i.e. a transmission that can continuously change its ratio from positive to negative values, consuming virtually no energy. With such a system, the actuator’s stiffness can be changed continuously at any time. Consequently, the main motor provides the mean positive power required at the ankle, while the stiffness is constantly adapted to render the desired torque. This approach is analogous to a decoupling between a booster motor injecting energy into a spring with constant power, and a valve only releasing the energy necessary for walking.

We propose a control strategy for the motor feeding the spring energy including a dynamical term stabilizing the spring elongation around a desired value. Figure 2 shows a simulation of the power flow when the controller is applied. As expected, the power delivered by the prosthesis is very close to the one provided by a healthy ankle [4].

![Power flow with VSA](Fig. 2. Power flow with VSA)

III. PERSPECTIVES

Our results tend to validate the use of a VSA based on an IVT for the design of an active ankle prosthesis. This design offers the unique advantage of minimizing the power flow of the output motor to the theoretical boundary (i.e. the mean positive power provided by a healthy ankle). So far, we assumed this IVT to consume no energy for changing its transmission ratio. Future work will focus on a realistic modelling of this IVT in order to propose guidelines for the design of light and energy efficient robotic devices. In particular, a question to be solved is whether the energy balance of the VSA using this realistic IVT is better than the one of a classical SEA working at resonance during steady-state walking, and close to resonance nearby. We further expect to validate these results with a real platform.

REFERENCES


