An Extended Antagonistic Series Elastic Actuator for a Biologically Inspired Four-Legged Robot

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I. Background and Motivation

If compared with biological systems that routinely exhibit dynamic behaviors in complex environments, our legged robots still severely lack diversity in locomotion, from slow, feedback to fast, feedforward controlled motions. Existing robots are still energetically inefficient and lack performance and adaptivity when confronted with situations that animals cope with on a routine basis. Bridging the gap between artificial and natural systems requires not only better sensorimotor and learning capabilities but also the corresponding motion apparatus with variable elasticity. The use of springs in legged locomotion has been generally considered as important [1]. Elasticity of legs, partially storing and releasing energy during contact with the ground, allows to achieve not only stable, but also rapid and energy efficient locomotion. Consequently, it is essential to work out principles of biological systems and transfer these to robot design, aka. mechanical intelligence [2]. A further key component of versatile and energy-efficient robots that move in a-priori unknown environments are proper actuation modules [3]. The main question is whether an actuation module always needs to enable the adjustment of the physical stiffness, and whether we need complex hardware mechanisms to gain humans' resp. animals' performance. Furthermore, it should be noted that only the interplay of all joints and their actuators constitute the overall performance of one leg resp. foot. In [3] a good overview of the different actuator designs is given, without focus on applications. In this presentation we will look at three different actuator designs with focus on implementation and integration within a 4-legged robot. Details about its design and model, shown in Fig. 1, can be found in [4].

II. Mechanics of the Actuator

The construction of the used drive is inspired by the functional principles inherent to the elastic and antagonistic muscle and tendon apparatus of the human arm [5] and has been tested thoroughly in the Biorob arm [6]. It is based exclusively on the application of the series elasticity in the drive in combination with an adequate positioning sensor system at the driving ends and in the joints. Each bionic drive consists of a conventional rotary electric actuator which is elastically coupled to the actuated joint by means of a pair of cables and springs. The cables are attached antagonistically

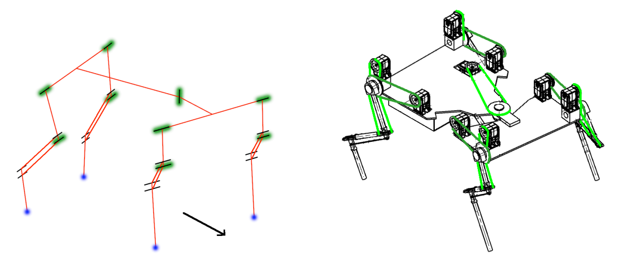

Fig. 1. On the left-hand side the skeletal structure of the model is shown. The joints highlighted in green are actuated. The feet are modeled as point masses at the current state. The black arrow marks the walking direction. On the right-hand side the CAD design is depicted.

to the end of the actuated link, and thus, the actuation module can be considered as an extended antagonistic SEA. However, compared to SEAs, this principle of actuation allows different possibilities of feedback and feedforward control and analysis, although the mathematical models are similar to a high extent. One main difference is the possibility of pretension/preload which reduces/avoids the problem of backlash and play. Another advantage is the reduction of damages of the motors. By using this bionic drive for the motion generation of a legged robot we not only demonstrate another useful application of this drive, but also demonstrate the potentials of this actuation module in the area of elastic control of legged robots.

III. Method and Control of the System

Feedforward control of the robot, divided into a central and decentralized part, can be achieved by the adjustment of several parameters. To affect the segment movement, however, it is sufficient to adjust the spring stiffness, i.e., the segment can even spin further than the motor actually allows. The biological leg allows such over spinning by the biological configuration of several muscle groups of which some are redundant and have different spring stiffnesses. Since the deployed springs in each actuator have predefined mechanically constant stiffnesses, we can not change the physical compliance, but by dynamically adjusting the equilibrium position of the spring, i.e., a different motor triggering, we can adjust the virtual stiffness. We refer to this concept as emulated spring stiffness. This concept enables many different gaits. Although in experiments the emulated spring performs the change at a later point of time, the transition can be performed actually much quicker than with manual methods, where the hardware has to be manipulated.

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IV. Discussion

The here proposed method requires neither prior knowledge about the model nor any sensors. The additional computational time for the variable virtual stiffness is insignificantly small and can therefore be ignored. Furthermore, the algorithm can be applied to any joint. For fast periodical motions the joint positions approximate the motor positions quite well. Besides, the emulated stiffness concept does not require any additional motor, and thus, does not result in additional weight of the actuator. The proposed actuator is passive compliant containing two elastic elements, springs that can store energy. We also noticed that for the intended application within the 4-legged robot an independent adjustment of rest position and spring stiffness is not necessary. We compared our concept to other compliant actuators, picking out from the group of active compliance the torque-controlled/virtual compliance concept as used in the DLR lightweight arm Justin [7] and from the group of passive compliance the MACCEPA [8] as used in the biped Lucy. Results at this stage of investigations show that the proposed new concept has the potential to be used in legged robots. Compared to other compliant actuators the mechanics of the proposed actuator can be considered as rather simple. Furthermore, we experience performance gains in the sense of multimodal locomotion possibilities. The design of such bionic drive will be even more advantageous if a prior analysis is performed to choose and determine the necessary force-elongation characteristic of the springs as well as the resulting compliance characteristic of the overall system.

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