ENHANCING HUMAN LOCOMOTION WITH BIARTICULAR SOFT EXOSUIT

Arjang Ahmadi[1], Vahid Firouzi[1], Dennis Haufe[1], and Maziar Ahmad Sharbafi[1]

[1]Lauflabor Locomotion Lab, Institute of Sport Science, Center for Cognitive Science, TU Darmstadt, Germany

Abstract

Biarticular actuation, inspired by the biarticular muscles in the human body, introduces a new level of sophistication to exosuit design. In this paper, we are explaining our newly developed BiArticular Thigh EXosuit (BATEX) which combines compliance and biarticularity as two bioinspired design features. BATEX design involves two elastic actuators per leg, called HAM and RF artificial muscles, inspired from hamstring and rectus femoris muscles. The HAM actuator applies assistance force in early stance and late swing, while the significant contribution of the RF actuator is at late stance. We conducted experiments with four healthy subject with no gait abnormalities to test the functionality of the BATEX. Based on the subject's self explanation, they feel assistance and a clear difference to the transparent mode in which rubber bands are disconnected from the shank and motors are off.

Keywords: Bioinspired exosuit, Biarticular actuation

1. INTRODUCTION

Soft wearable robots, called exosuits, are designed to be worn by individuals to enhance their performance and provide assistance during different activities [1]. The coordination of these devices with biological limb is essential as these devices work in parallel to the biological joints. Integration of bioinspiration into design and control strategies, allowing for seamless interaction between the human body and these assistive devices, and lead to more effective and efficient wearable robotic devices. Incorporating compliant and biarticular actuation mechanisms in design of exosuits is a bioinspired design concept that can be borrowed from musculoskeletal system.

Compliant actuation, characterized by the use of elastic components to generate and transmit forces, enables wearable robots to emulate the natural compliance of human muscles and tendons. These components absorb and inject mechanical power during specific phases of walking, contributing to the more efficient actuation [2]. Further, this design approach enhances user comfort and facilitates a more natural interaction between the exosuit and the wearer [3].

Biarticular actuation, inspired by the biological musculoskeletal arrangement , introduces a new level of sophistication to exosuit design. These actuators span multiple joints and contribute to optimizing energy expenditure during gait by providing a mechanism for redistributing forces and power among joints. Also, biarticular actuation could reduce control dimensionality through morphological computation, if they are designed carefully [2,3].

In this paper, we are explaining our newly developed BiArticular Thigh EXosuit (BATEX) which combines compliance and biarticularity as two bio-inspired design features.

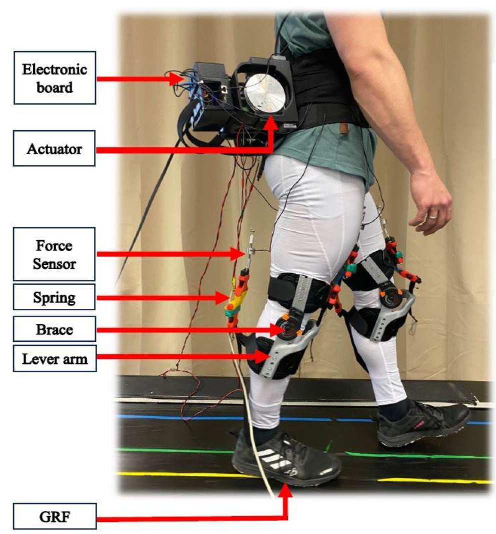

Figure 1: BATEX exosuit system components: Sagittal view of the exosuit in the experimental trial of treadmill walking. The actuation unit for each leg includes one motor and two serial springs.

2. DESIGN

The BATEX exosuit (shown in Fig. 1) is designed and developed to assist both hip and knee simultaneously. This exosuit structure involves two elastic actuators per leg, so-called HAM and RF artificial muscles inspired from hamstring and rectus femoris muscles in human leg. Because of the negligible overlap between these two muscles' contributions (co-contraction), we expect one motor to be sufficient to derive both actuators, which will introduce another design advantage. Here, HAM artificial muscle assistance force applies in the early stance and late swing, while the significant contribution of the RF artificial muscle is at late stance and early swing.

The soft wearable components of BATEX consist of a waist brace, two thigh braces, and two shank braces. The HAM and RF serial compliant arrangements consist of rubber bands, Bowden cables, force sensors, and connecting straps. Bowden cables transmit the force from the pulley to the serial elastic elements. Force sensors are also attached at the connection points of the rubber bands and the shank segment to measure the transferred force. A rigid (orthisis-like) structure is used at the knee joint to align the RF artificial muscle with the thigh segment and prevent unpleasant forces from the RF spring on the knee joint (patella). Also, this component keeps the knee lever arms of both RF artificial muscles around 4 cm, as shown in Fig. 1.

The actuation box is placed in a backpack, including motors, gears, electronic boards, and pulleys. The total mass of the exosuit is 4.2 kg, which is distributed mainly close to the whole body center of mass. The spring's stiffness is an important parameter that significantly affects actuation bandwidth. We set the stiffness of the rubber bands in HAM and RF artificial muscles to 1.1 kN/m and 0.7 kN/m, respectively.

3. FUNCTIONALITY TEST

we conducted experiments with four healthy subjects (2 male, 2 female, 31 ± 3 years, 70 ± 9 kg, and 172 ± 7 cm) with no gait abnormalities. The subjects participated in the study after signing the consent sheet approved by TU Darmstadt ethical committee. All experiments involved a 20-min warm-up walking session to help subjects adapt to the experimental setup, followed by 5-min assisted walking sessions.

To derive the actuators, we employed a neuromechnanical controller introduced in [2]. This hybrid controller locks the motor in the swing phase to simplify it to a set of two passive biarticular springs and employs the force modulated compliance (FMC) controller in the stance phase [2]. The FMC controller emulates a variable spring whose stiffness is tuned using the ground reaction force feedback (see [2,3] for more information). We utilized the force data from the instrumented treadmill in our controller, which can be replaced by insole sensors in future to make it applicable for overground walking.

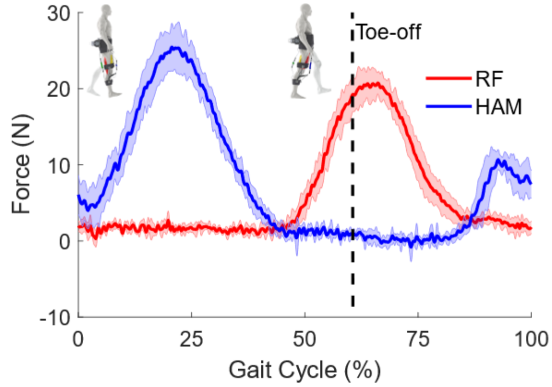

Figure 2: Measured force profiles of biarticular artificial muscles from assisted walking experiment.

Fig. 2 shows the force produced by HAM and RF artificial muscles. This figure shows the contribution of the HAM artificial muscle in the late swing and early stance and contribution of RF artificial muscle in late stance and early swing as aimed in the design of the exosuit.

Based on the subject's self explanation, they feel assistance and a clear difference to the transparent mode in which rubber bands are disconnected from the shank and motors are off. We are conducting further experiments with metabolic and EMG measurements.

4. OUTLOOK

Bioinspired exosuits like BATEX could assist healthy or impaired people in daily life. Further, we expect that the BATEX could support reducing perturbation and improve postural stability. In addition, BATEX could be used to assist people in different gaits, e.g., in professions requiring timely locomotion. To investigates these potential aspects, we need more experimental studies.

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