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Exoskeleton Controller Based on Soft Sensor Inputs

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I. Motivation

Exoskeletons have the potential to greatly enhance endurance during long, exhausting mobility tasks [1], [2], however, commercially available sensors like IMUs, used to measure body movement and muscle activation, are rigid and can cause discomfort when worn between the body and an exoskeleton system. Advances in soft sensor technology enable more comfortable movement measurement [3].

Existing control approaches, even those using soft sensors, often rely on indirect subject walking gait pattern estimation methods like muscle activation detection and human preference optimization [4], [5]. These methods may lead to imprecise gait event detection and are typically time-consuming. Our proposed controller scheme utilizes solely lightweight, comfortable fabric sensors for kinematic measurements, directly estimating the user's walking gait pattern. This proposed approach aims to reduce user effort by supplying ankle torque assistance during the foot push-off event.

II. Methodology

The exoskeleton torque profile is designed using two polynomial functions parameterized by gait phases [6]. Key components of the torque profile design include gait duration, rise time, peak time, fall time, and peak torque, as depicted in the lowest plot of Fig. 1(b).

The peak exoskeleton torque is designed to coincide with the toe-off event, occurring when the hip joint reaches its maximum extension angle. Rise and fall times are set at 90% and 110% of the peak torque time, respectively, with the peak torque value chosen to be proportional to the maximum hip extension value of the hip sensor reading. Subsequently, the heel strike event is estimated and used to define the gait duration by leveraging the knee soft sensor reading.

III. Preliminary results and discussion

The fabric sensor developed in the Faboratory Lab at Yale University [7] has been utilized in this work. The fabric sensor was attached over the hip and knee joints of both legs along the sagittal plane, as shown in Fig. 1(a). The subject was asked to walk on a Motek M-Gait treadmill with a speed of 1.0 m/s for one minute while wearing a pair of ankle exoskeletons (ExoBoot, Dephy, Inc., Boxborough, MA, USA). A Vicon Vero motion capture system is used to obtain the ground truth for the gait event timing.

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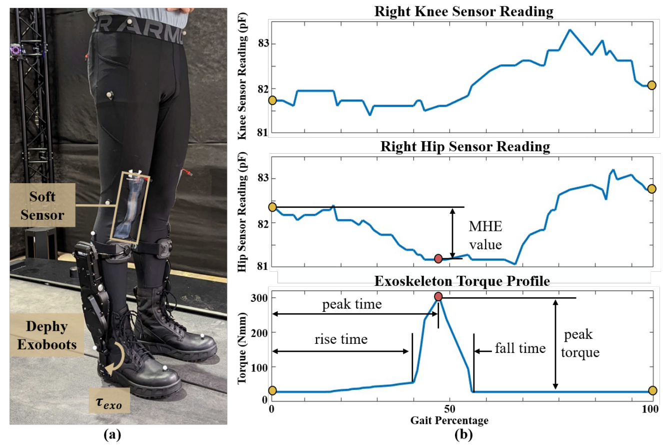

Fig. 1: (a) The hardware setup is utilized to acquire sensor data and execute torque commands for the proposed controller. (b) Soft sensor readings and torque commands during a single walking gait cycle. In these plots, the yellow dot indicates the heel strike event, while the red dot represents the maximum hip extension (MHE) event.

Figure 1(b) illustrates the accurate estimation of gait events, with exoskeleton torque exerted at the precise time instant, coinciding with the maximum hip extension event. The proposed controller aligns the peak exoskeleton torque time with the subject's foot push-off event, potentially decreasing the manual tuning time for torque parameters. This design results in a biomimetic exoskeleton torque profile, ultimately reducing the user's joint effort. We are extending this work to design effective exoskeleton control for different subjects.

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