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Flexible Assistive Robots Through AFO-Based Intention Detection

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Recent findings in rehabilitation robotics suggest that therapies are more successful when the patient actively participates to perform the intended movement, giving rise to the concept of "assist-as-needed" [1]. Commercial solutions for lower limb rehabilitation still rely on older paradigms based on the stiff control of a reference trajectory specified by the experimenter [2]. This way, the patient is completely supported by the robot, regardless of his own contribution or capabilities. We propose a new approach to provide assistance-as-needed during cyclical movements. This approach is based on adaptive oscillators [3]. Oscillator-based methods are appealing in the context of rhythmic movement assistance, in our new approach, we speculate that the adaptive oscillator will synchronize with the user's movement in a similar way as the therapist would do when assisting the patients during exercise. Our contribution focuses on two experiments. In the first [4] we focused on (quasi-) sinusoidal movements about the elbow joint. The artificial oscillator was based on an augmented Hopf oscillator [3]. From a (quasi-) sinusoidal input, this dynamical system is able to extract the movement features, namely frequency, amplitude and offset, while keeping its output phase synchronized with the input. Therefore, a smoothed but synchronized estimate of the input signal and of its derivatives can be obtained. The main advantage of this approach with respect to classical filtering is none of the estimates is delayed with respect to the actual position, velocity, and acceleration. This is because the oscillator exploits the a priori knowledge that the movement is periodic.

Using the estimates of position, velocity, and acceleration, an estimate of the applied torque can be obtained using an inverse dynamical model. Finally, a fraction of this torque can be fed back to the user, using an assistive device. This approach was successfully applied to healthy individuals using an elbow exoskeleton [4]. Fig. 1(a) shows the biceps and triceps EMG measured on a representative participant during cyclical flexion-extension of the elbow of constant amplitude and frequency. The figure reveals that a significant decrease of the participant effort was obtained by switching the assistance on (black dots), while this decrease was instantaneously washed out once assistance was removed (dark gray dots). Because of the oscillator intrinsic adaptivity, this approach left the user free to change the movement amplitude and frequency, as demonstrated by complementary data.

A second experiment was performed to translate this approach for a more functional task, namely walking. For this aim, we used the LOPES, a lower-limb exoskeleton robot for interactive gait rehabilitation. The dynamics of walking introduce two extra challenges with respect to the former design: the joint trajectories are no longer sinusoidal; and

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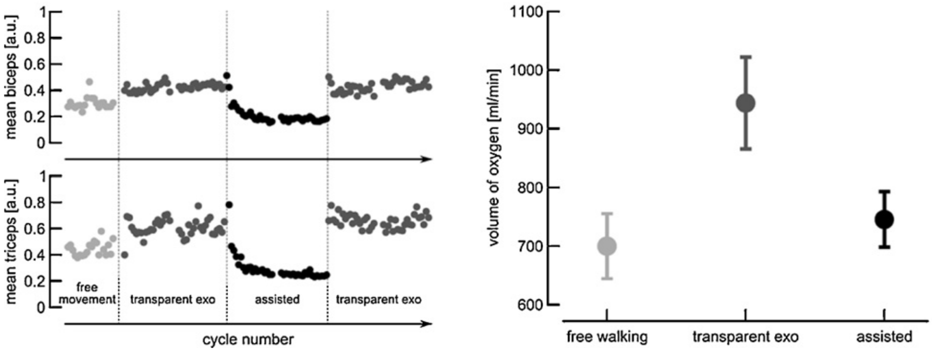

Fig. 1. (a) Experiment 1. Average of the rectified EMG for the biceps (top) and triceps (bottom) of a representative participant. The last 20 cycles of the condition without wearing the exoskeleton (light gray) are shown, and the first and last 20 cycles of three trials wearing the exoskeleton (dark gray: trials 1 and 3 without assistance (transparent mode); black: trial 2 with some assistance (50%) provided). (b) Experiment 2. Volume of consumed oxygen during walking. The figure shows the average and standard deviation of 3 minutes of stationary walking on a treadmill in a free mode (no exoskeleton, light gray), with the exoskeleton controlled in transparent mode (dark gray), and with the exoskeleton providing some assistance (black), assistance (50%) provided).

the inverse dynamical model cannot be easily derived because of multi-joints dynamics and ground contact. The first challenge can be solved by augmenting the adaptive oscillator with a non-linear filter learning the non-sinusoidal envelope of the periodic input [5]. To avoid the difficulties related to the second challenge, we derived a model-free version of our approach. Adaptive oscillators can also be used for signal prediction. The predicted position can be used as an attractor for a compliant force field acting on the user's joint, applying a torque corresponding to a viscoelastic field centered on the predicted future position. Figure 1b shows preliminary results obtained with this approach for a single healthy participant. We quantified the participant's metabolic cost during stationary walking based on the volume of consumed oxygen. While wearing the exoskeleton increased the metabolic consumption with respect to free walking, this increase was almost entirely compensated by our assistance algorithm. Again, the participant was free to shape the joints trajectories according to his intentions, since the oscillator continuously adapted.

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