Evaluation of Force Tracking Controller with Soft Exosuit for Hip Extension Assistance

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Abstract This abstract describes the design and experimental evaluation of a force tracking controller for hip extension assistance utilizing a soft exosuit connected to a tethered off-board actuation system. The new controller aims to improve the force profile tracking capability and demonstrate its advantages over our previously reported work. The controller was evaluated by one healthy participant walking on a treadmill at 1.35 m/s. Results showed that the system can deliver a predefined force profile robustly with a 200 N peak force. The measured peak force value using force controller was 198.7 ± 2.9 N, and the root-mean-squared (RMS) error was 3.4 N (1.7 % of desired peak force). These results indicate that the force control reduces peak force variability and improves force profile tracking capability.

1 Introduction

In recent years we have seen exciting results demonstrating that exoskeleton devices can reduce energy cost during walking [1–4]. We have been developing soft wearable robots we call exosuits that are intended to provide a more conformal and compliant means to interface to the human body. An exosuit uses textiles and apparel, resulting in minimal resistance to natural human motion and does not add significant inertia to the lower extremities. In prior work, we have implemented a force-based position control (referred as position controller hereafter) [4–6] to indirectly regulate force to reach the desired peak values. This approach has proved

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successful to date in our ankle and hip actuation systems where a desired force can be achieved by having the actuator follow a prescribed position profile. The force magnitude is then regulated by monitoring the force level on a step by step basis.

However, from other work on wearable robotic systems, the advantage of direct force control is apparent, as it can potentially minimize the peak force variability and precisely track desired force profiles at a joint [7]. This can enable precise torque delivery to understand optimal assistive device design [8]. Further, force control is potentially more robust to variations in gait kinematics as it keeps minimizing force error regardless of joint position.

To accurately regulate force delivery in exoskeletons, force control methods like iterative learning-based force control [7] have been studied in rigid devices. However soft exosuits impose particular challenges for force tracking because stiffness of the human-exosuit interface is nonlinear, and the system presents varying system characteristics both from human (e.g. gait variability) and the electromechanical system (e.g. suit stiffness changes and Bowden cable efficiency). To address this, we developed a force tracking controller for hip extension assistance and evaluated its efficacy during treadmill walking.

2 Material and Methods

The hip extension soft exosuit system is composed of a mono-articular hip exosuit and a reconfigurable multi-joint actuation platform previously described [6] and the setup is shown in Fig. 1. The textile components of the hip exosuit include a waist belt, two thigh braces and two elastic straps on the lateral side of each leg to prevent migration of the thigh brace [6].

2.1 Sensing and Actuation

Sensors of this soft exosuit system included an Inertial Measurement Unit (IMU) and one load cell per leg. The thigh angle was measured with an IMU

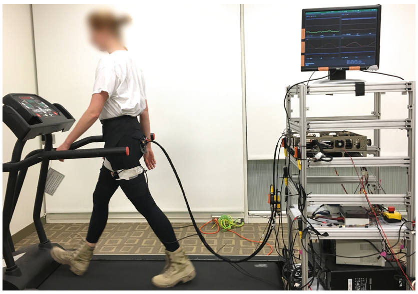


Fig. 1 Hip extension soft exosuit system. IMU measures thigh angles. Two sets of Bowden cables are connected between the multi-joint actuation platform and the exosuit to provide hip extension assistance during walking. The assistive force is transmitted from the multi-joint actuation platform to the wearer

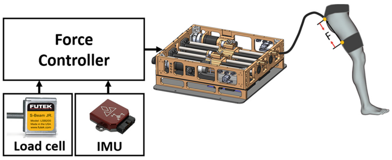


Fig. 2 Electromechanical sensing and control system. The timing of the motor force and position control profile is generated in real-time based on sensor input from thigh mounted IMU and load cell

(VN-100, VectorNav Technologies, USA) as shown in Fig. 1. The controller detects maximum hip flexion and the stride time is estimated as the time between two consecutive maximum hip flexion events [6]. The data acquisition card (PCI-6259, NI, USA) acquires the digital IMU and analog load cell signals. Then the controller processes the signal and sends a reference voltage to the Copley motor controller (ACP-090-36 Accelnet, USA) for the Maxon EC-4 pole brushless motor Fig. 2.

2.2 *Force Tracking Controller Description*

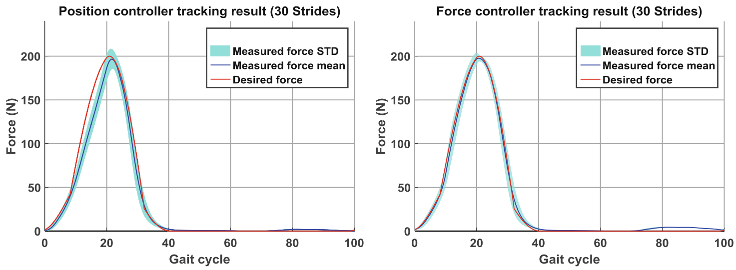
The objective of the force tracking controller is to minimize peak force variability and enable force profile tracking. This is motivated by the desire for precise and robust force manipulation to understand the relation between force delivery and human walking metabolics.

The force controller has both position and force control loops to deliver sinusoidal force profile with 200 N peak. The bio-inspired force profile is a scaled version of the biological hip moment, designed to provide a joint torque equivalent to approximately 30 % of the biological hip extension moment.

3 Results

The force tracking controller was evaluated by one healthy participant walking on a treadmill at 1.35 m/s. The objective is to evaluate if the controller delivers reliable and accurate force profile to the participant on a step-by-step basis.

In a continuous walking session, the participant walked for 2 min using the position controller, and then walked for 2 min using the force controller. The measured force in the last 30 strides was used for analysis. The peak force using position controller was 196.3 ± 11.2 N, and the root-mean-squared (RMS) error was 9.5 N (4.8 % of desired peak force) as depicted in Fig. 3(a). The peak force using force controller was 198.7 ± 2.9 N, and the RMS error was 3.4 N (1.70 % of desired peak force) as depicted in Fig. 3(b). It is apparent that the force controller demonstrated better force tracking performance especially in the 10-20 % gait cycle region comparing Fig. 3(a) and (b).



(a) (b)

Fig. 3 Force tracking results using the position controller **a** and the force controller **b**. The results were from a healthy participant at 1.35 m/s steady state walking for 30 strides

4 Conclusion

We presented a force tracking controller for hip extension assistance. The experimental results demonstrate the effectiveness at steady-state walking in terms of reduced peak force variability and enhanced profile tracking capability. Further evaluation will include force profile tracking results for different subjects with gait change.

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