Bioinspired Control of Trunk Dynamics to Enable Uphill Walking

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Summary

This study investigates the role of trunk dynamics in uphill locomotion by utilizing a 2D spring-loaded inverted pendulum (SLIP) model that incorporates a trunk as the upper body. By implementing a Force-Modulated Compliance (FMC) controller, which adjusts compliance based on feedback from leg forces, we demonstrate that regulating upper body orientation generates the necessary forces for stable uphill walking. The findings highlight the significance of upper body dynamics and the potential of bioinspired FMC controllers for assistive devices in uphill walking scenarios.

Introduction

The spring-loaded inverted pendulum (SLIP) model serves as a fundamental framework for studying locomotion [1]. However, since its energy level remains constant, it cannot move uphill without external input. This study investigates whether incorporating a trunk into the SLIP model and utilizing trunk dynamics can facilitate uphill locomotion.

Methods

We extended a 2D SLIP model by integrating a trunk attached to the hip joint (see Fig. 1). The trunk represents the upper body and is stabilized using a Force-Modulated Compliance (FMC) controller [2]. This bioinspired controller adjusts hip compliance stiffness based on leg force feedback (Eq. 1). The FMC controller emulates the Virtual Pivot Point (VPP) concept observed in human walking [2]. The VPP says that ground reaction forces (GRFs) intersect at a point above the center of mass (CoM) in a coordinate frame attached to CoM and aligned with upper body orientation.

$$\tau_h = cF_l(\psi_0 - \psi) \tag{1}$$

where τ_h is the hip torque, c is a constant, F_l is the leg force, ψ is the angle between the upper body and leg, and ψ_0 is the rest angle, defined as the angle between the upper body orientation and the hip-VPP line. To analyze the effect of trunk dynamics on uphill walking, we optimized model parameters and initial conditions for a 1% slope. Using these optimized values, we simulated slopes ranging from 0.1% to 2% by varying only ψ_0.

Results and Discussion

Our results indicate that trunk dynamics play a crucial role in generating the necessary energy for uphill walking. Forward trunk lean, achieved by decreasing ψ_0 in the FMC controller, facilitates this process (see Fig. 1). A lower ψ_0 increases hip torque during the first half of the stance phase and reduces it in the latter half (see Fig. 1). This hip torque modulation produces a force perpendicular to the leg at the foot, reducing the braking component and increasing the propulsive component of the GRF, enabling uphill locomotion.

This study highlights the crucial role of upper body dynamics in uphill walking and showcases the effectiveness of the bioinspired FMC controller in producing stable uphill gait patterns. However, the model struggles to generate gaits on higher slopes, potentially requiring active elements in the legs. The FMC controller, previously implemented in assistive devices for level-ground walking [1], holds promise for integration into assistive technologies for uphill walking.

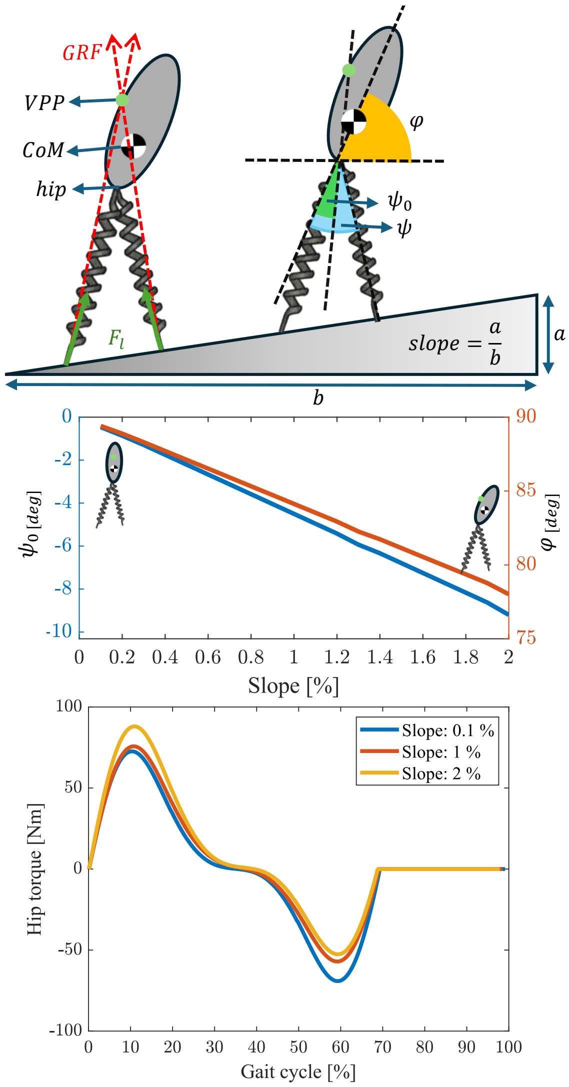

Figure 1: (Top) The SLIP model with a trunk walking uphill. (Middle) The relation between slope (ranging from 0.1% to 2%), the FMC parameter (ψ_0) and the upper body orientation with respect to the ground (ϕ). (Bottom) The hip torque in different slopes.

Acknowledgments

Supported by the German Research Foundation within RTG 2761 LokoAssist under grant no. 450821862.

References

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