Time-varying ALIP based Footstep Planner for Underactuated Humanoid Digit Robot Walking on a Swaying Rigid Surface

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I. INTRODUCTION

Humanoid walking on dynamic rigid surfaces (DRSes), such as the floors on trains, planes, and ships, poses challenges due to the associated complex robot dynamics [1]–[3]. We propose a real-time footstep planner that explicitly treats underactuated walking dynamics and time-varying DRS motion. The first main contribution is planner design via an angular momentum-based linear inverted pendulum model on the DRS (ALIP-DRS). The second main contribution is the construction of provable and sufficient stability conditions based on the ALIP-DRS model.

II. HIERARCHICAL PLANNING FRAMEWORK

This section presents our proposed hierarchical planning framework for achieving stable walking on the DRS with the Digit robot. The framework consists of three layers that effectively address the challenges posed by the hybrid, time-varying, and nonlinear dynamics of underactuated robots. At the higher layer, an ALIP-based planner [4] that is aware of the DRS motion profile generates footstep commands. This layer is derived based on the proposed ALIP-DRS model as well as the provable stability conditions for the ALIP-DRS. The middle layer plays a crucial role in generating full-body reference trajectories that align with the simplified ALIP model, rendering the full-order robot dynamics to the ALIP model. Moreover, the middle layer ensures accurate translation of desired footstep locations into reliable swing foot trajectories for precise tracking by the lower layer controller. The lower layer controller, implemented as either input-output linearizing control [1] or inverse kinematics control [5], ensures stable execution of planned foot placements, stabilizing the underactuated full-order robot dynamics.

III. SIMULATION RESULTS

This section compares our proposed DRS planner and a previously developed planner [6], referred to as the static rigid surface (SRS) planner. The evaluation task is robot navigation through a narrow pathway on the DRS, a scenario commonly encountered in ships ad airplanes. Experiment results (Fig. 1) show that our DRS planner enables the robot to regulate its forward speed accurately and successfully traverse the narrow pathway without deviating from the designated trajectory. Yet, the SRS planner exhibits less accurate speed regulation, causing deviation from the desired path and collisions with the surrounding walls. This comparative result clearly highlights the superiority of our proposed approach.

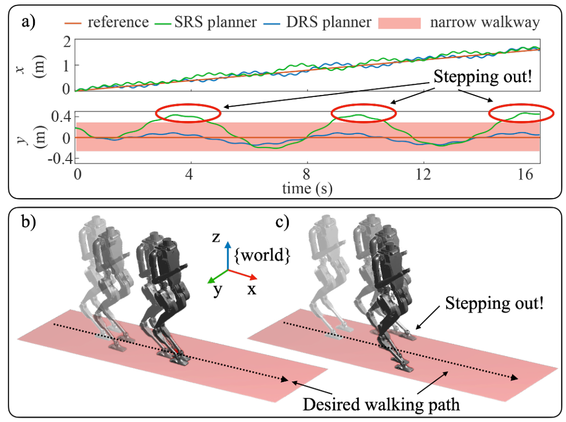

Fig. 1. Comparison of global position tracking capability between the SRS and the DRS planner. a) Plots show superior tracking performance of the DRS planner in the forward direction, with the Digit staying within the designated walking area. b) Digit walking on a narrow DRS walkway under the DRS planner. c) Digit walking on the same walkway under the SRS planner, resulting in stepping outside the walking surface.

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