Precision Jumping with a SLIP-like Robot

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Abstract— **We developed a deadbeat foot placement hopping controller for an untethered monopedal robot, Salto-1P. The controller uses a third order Taylor series approximation to an offline SLIP-like dynamic model and performs well on the physical platform. Due to the robot's similarity to the SLIP template, control is based closely on the SLIP-like model without adjustment required for the physical platform. We found that the SLIP-like model's horizontal velocity at takeoff becomes more sensitive to the touchdown leg angle as the hopping height increases.**

I. INTRODUCTION

We consider a SLIP-like hopping model to develop deadbeat foot placement hopping control in which the robot can place its foot at a desired foothold point after only one intervening stance phase.

During flight, a jumping robot has no control over the motion of its center of gravity (CG) without specialized means to apply large forces in the air. To reach a desired foothold, the robot must set its velocity at takeoff to aim its flight path towards the foothold. A SLIP-like robot's takeoff velocity can be changed by setting stance initial conditions like leg angles at the previous flight's touchdown as in [2]. In [1] we demonstrated that this is effective for robots like Salto-1P with short stances and high accelerations.

II. METHODS

In order to predict takeoff velocities resulting from certain touchdown conditions, we simulated stance in a Matlab rigid body simulation matched to the physical parameters of Salto-1P. Salto-1P's mechanics are very similar to the SLIP-model, leading to the following simplifications.

Salto-1P's moment of inertia about its lateral and longitudinal axes are both approximately 130×10^{-6} kg m^2. Since the robot weighs 0.103 kg and its CG is 0.10 m above its foot with the leg fully retracted, the robot's moment of inertia about its foot is dominated by the CG distance from the foot and is not significantly changed by the robot body's heading. Since the robot's foot moves along a straight line coincident with the CG and its moment of inertia is nearly the same at all headings, the robot's stance phase is insensitive to heading and its touchdown yaw angle can be neglected.

This material is based upon work supported by the United States Army Research Laboratory under the Micro Autonomous Science and Technology Collaborative Technology Alliance and the Army Research Office Grant No. W911NF-18-1-0038.

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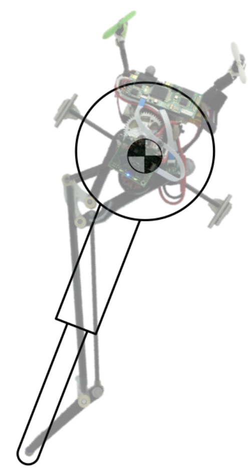

Fig. 1. Salto-1P's CG-dominated inertia and straight-line foot motion make it very similar to the SLIP template and enable direct application of a controller derived from simple models on the physical platform.

Furthermore, since the balanced inertial tail's angular velocity is kept low by braking during stance phase, the tail's angular momentum is small compared to the angular momentum due to the motion of the robot's CG. As with the robot's yaw heading, the tail angle and angular velocity are also neglected. With the above assumptions, the robot's behavior is similar to a SLIP-like point mass and motor-controlled leg force.

Since neither this SLIP-like model nor the canonical SLIP model has a closed form solution, we numerically simulated stance trajectories for 16,170 initial conditions. The robot's control actions are selected using a third order polynomial curve fit to these offline simulation results.

III. RESULTS

Since Salto-1P behaves very similarly to the SLIP-like model, no modifications to the controller were required for operation on the physical robot. We demonstrated that the controller's foot placement accuracy with the physical robot is high enough that the robot can jump up onto a chair and desk and then back down as shown in Fig. 2.

As in Raibert's early hopping control work [2], Salto-1P's takeoff horizontal velocity is highly sensitive to touchdown leg angle. In this work, we found that this sensitivity of takeoff horizontal velocity to touchdown leg angle increases as the robot's vertical velocity increases as shown in Fig. 3. This means that a given touchdown leg angle error will

Workshop on Modeling and Control of Dynamic Legged Locomotion: Insights from Template (Simplified) Models
IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) 2018, Madrid, Spain

produce larger and larger horizontal velocity errors as the robot's vertical velocity and hopping height increase. As a result, the robot's touchdown leg angle must be more accurate as the hopping height increases if it is not to miss its foothold.

Fig. 2. Salto-1P jumps up onto a chair and desk (trajectory in blue), then back down (not shown). The chair seat is 0.44 m high and the desk is 0.71 m high. The robot is 0.32 m tall with its leg extended to its maximum length of 0.15 m.

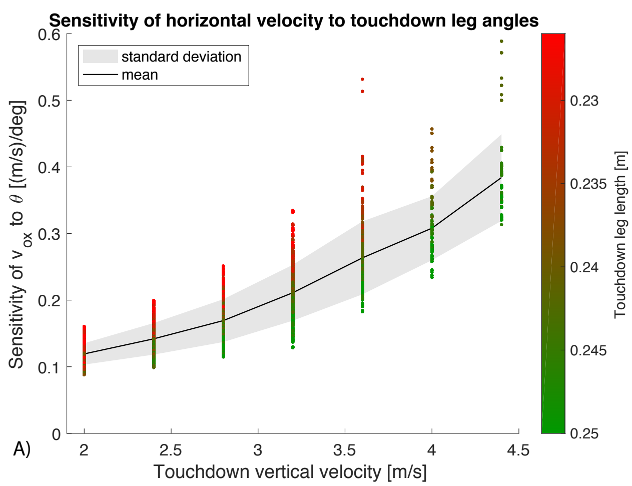

Fig. 3. Takeoff horizontal velocity v_{ox} sensitivity to leg angle θ increases with increasing vertical velocity (equivalent to increasing hopping height).

References

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