Understand gait transitions in Jerboas using a template model

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I. Introduction

Jerboas quickly switch among three different gait patterns (running, hopping, and skipping) that are associated with distinct accelerations, rather than speeds [1]. It has been hypothesized that these bipedal gait transitions are likely to enhance their maneuverability and evasion ability. However, it is difficult to understand the underlying dynamics of these locomotion patterns due to the large number of degrees of freedom expressed by the animals.

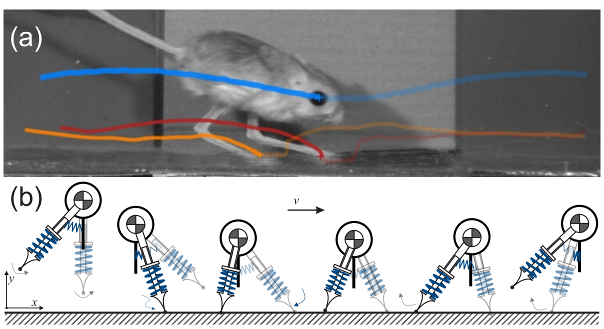

Fig. 1. Example of a bipedal skipping gait (a) as exhibited by the Lesser Egyptian jerboa (*Jaculus jaculus*). The proposed template model (b) is able to reproduce the same footfall pattern.

II. Methods

A. Unified SLIP Model

We developed a unified Spring Loaded Inverted Pendulum model with swing leg motion. With a single set of parameter values, this model is capable of reproducing a large number of gait patterns at various speeds including running, hopping, and skipping as shown in Fig. 1(b). Also, we found these footfall patterns can be identified as bifurcations from a simple jumping in-place motion [2]. Therefore, this template model is suitable for modeling the transient gait transitions in jerboas.

B. Trajectory Optimization

To understand how jerboas change from one gait to another, we employ an optimization approach and use the proposed model to reproduce observed patterns of jerboa gait transitions. We recorded jerboa locomotion along a straight track from a lateral view at 250 fps and recorded ground reaction forces with an instrumented 2-axis force platform as shown in Fig. 1(a). During the simulation of a gait transition, the simulated model trajectory can be defined as $\mathbf{X}_{sim} = [x, y, \alpha_l, \alpha_r]$ which includes the center of mass position as well as leg angles. The simulated GRFs can be computed as $\mathrm{F}_{sim}(t, \mathbf{p})$ which are a function of time t and also depend on a set of model parameters $\mathbf{p}$ (see [3]). In the i-th trail, the residual function c_i quantifies how well the model predicted the kinematics and dynamics of the locomotion pattern in jerboas:

$$\mathrm{c}_i(\mathbf{X}_i, \mathbf{p}) = \int_0^{T_i} \left\| \mathrm{X}_{sim,i}(t, \mathbf{p}) - \hat{\mathbf{X}}_i(t) \right\|^2 + \left\| \mathrm{F}_{sim,i}(t, \mathbf{p}) - \hat{\mathrm{F}}_i(t) \right\|^2 dt. \tag{1}$$

$\hat{\mathbf{X}}$ and $\hat{\mathrm{F}}(t)$ denote the actual trajectories of jerboas and the ground reaction forces, respectively. We define the cost function as the summation of the residuals in total of n trails and the value of this cost function is minimized as an unconstrained optimization problem with a single set of parameters $\mathbf{p}$:

$$\mathrm{C}_{opt} = \min \left\{ \sum_{i=1}^{i=n} \mathrm{c}_i(\mathbf{X}_i,\ \mathbf{p}) \right\} \tag{2}$$

III. Best Possible Outcome

We will systematically model all possible gait transitions from the trails and determine to what extend these transition processes can be captured by the proposed SLIP model. Our expectation is that, with the limitations of the planar model, these transient behaviors can be simplified as non-periodic mechanical oscillation modes of the same mass-spring system. Based on the identified results, we will investigate how and when jerboas switch locomotion patterns. Furthermore, this study can inform controller design of legged robots to achieve more agile motion.

References

[1] T. Y. Moore, K. L. Cooper, A. A. Biewener, and R. Vasudevan, "Unpredictability of escape trajectory explains predator evasion ability and microhabitat preference of desert rodents," *Nature communications*, vol. 8, no. 1, pp. 1–9, 2017.

[2] Z. Gan, Y. Yesilevskiy, P. Zaytsev, and C. D. Remy, "All common bipedal gaits emerge from a single passive model," *Journal of The Royal Society Interface*, vol. 15, no. 146, p. 20180455, 2018.

[3] Z. Gan, T. Wiestner, M. A. Weishaupt, N. M. Waldern, and C. David Remy, "Passive dynamics explain quadrupedal walking, trotting, and tölting," *Journal of computational and nonlinear dynamics*, vol. 11, no. 2, 2016.