Optimal Running to Climbing Transitions on a Multi-Modal Quadrupedal Robot

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I. Introduction

Various animals are not only capable of moving in complex environments and various modes, such as running on varied terrain and up vertical surfaces, but can also skillfully and efficiently transition between these modes. Multi-modal legged robots capable of running and climbing, such as SCARAB, Bobcat, and Rise V2, are beginning to be developed, but rapid transitions between these modes remains difficult.

Cockroaches and small robots, such as DASH, accomplish these transitions with head on collisions with a wall [1]. However, for larger and more delicate robots, a more nuanced approach is needed. This work presents an optimization framework that is capable of identifying feasible trajectories in state and motor space that allow a quadrupedal robot to successfully navigate the transition between running and climbing while satisfying context specific constraints.

To illustrate this, we present an example trajectory that transitions the robot from steady state running at 1.3 body lengths per second to vertical climbing in a minimum time.

II. Methods

The trajectory optimization problem is formulated in Matlab using the `fmincon` solver and direct collocation methods for simulating the dynamics of the robot. The dynamics were obtained by modelling the robot as a rigid body with two compliant legs that moves in the sagittal plane.

A. Design Variables and Constraints

The design variables for the trajectory optimization were the six body states and the linear forces and torques on each leg throughout the trajectory. In the example case shown in Figure 1, the initial horizontal velocity of the robot was set to 0.4 m/s and the ending state was constrained to be above a minimum height and rotated by $\pi/2$ radians, with no constraints on impact velocity. Constraints were also added to respect the physical limitations of a robotic system, such as motor torque limits and maximum and minimum leg lengths.

B. Mode Scheduling

The hybrid dynamics of the running to climbing transition task require a mode schedule to determine an optimal trajectory. In the example trajectory, a mode schedule of 4 leg running - 2 leg rearing - flight was chosen. This is illustrated in Figure 1(i).

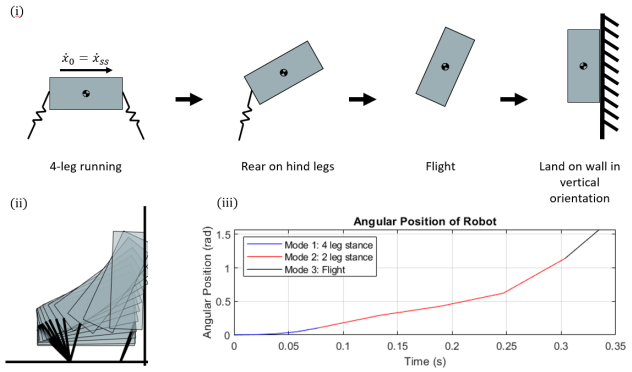

Fig. 1. (i) Depiction of the modes used to create a transition trajectory. (ii) Time-lapse animation of the example trajectory. (iii) Plot of θ vs time for the example trajectory. The trajectory satisfies constraints by starting at zero radians and ending at $\pi/2$.

III. Results & Discussion

The example formulation yields a trajectory of desired states and command inputs that successfully completes the transition from running to climbing while satisfying the constraints. The resulting trajectory spends the most time in the 2-leg stance mode and minimizes time spent on all four legs and in flight, as shown in Figure 1(ii) & 1(iii).

In ongoing work, we are exploring the robustness of the generated trajectories and testing them on our next generation multi-modal dynamic quadrupedal robot based on Bobcat [2]. This work has the potential to enable agile and efficient transitions from running to climbing in multi-modal dynamic legged robots.

References

[1] K. Jayaram, J.-M. Mongeau, A. Mohapatra, P. Birkmeyer, R. S. Fearing, and R. J. Full, "Transition by head-on collision: Mechanically mediated manoeuvres in cockroaches and small robots," *Journal of the Royal Society Interface*, vol. 15, no. 139, p. 20170664, 2018.

[2] M. P. Austin, J. M. Brown, C. A. Young, and J. E. Clark, "Leg design to enable dynamic running and climbing on bobcat," in *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 3799–3806, IEEE, 2018.