Exploration of contact models and uncertainty in the context of legged robots

William Yang and Michael Posa
University of Pennsylvania
yangwill@seas.upenn.edu.edu

I. Introduction

While legged robots have the potential to navigate in complex environments due to their ability to make intermittent contact with the world, their defining feature of intermittent contact is also a major source of complexity when developing controllers. Despite the importance of contact events, their effect on controller performance is still not well understood.

Many popular control strategies for legged robots exhibit a hybrid approach that switches controller modes depending on the contact mode. These hybrid controllers operate under the assumption of rigid body models and instantaneous impacts similar to many robotics simulators. However, when adapting these controllers from simulation to hardware, additional relaxations are often added to smooth the performance around impact events. The additions are needed because controllers for legged robots are particularly sensitive to impact events - the desired control strategy can change drastically between contact modes and any uncertainty can be exacerbated by applying the wrong control efforts. For this reason, common additions when porting controllers onto hardware will involve techniques such as blending controller gains [1] or simply applying zero torque around contact events. Although these strategies have had empirical success, they make heavy use of heuristics and there still lacks a principled explanation for why these strategies are effective.

II. Approach

I aim to better characterize the empirical uncertainty of these events and reevaluate current impact models. The contributions of an improved understanding of the empirical uncertainty of an impact event may include an explanation for why present heuristic strategies are effective, and may point to a new control strategy that is more robust to the uncertainties in contact.

This will likely require a reevaluation of the rigid body assumption about impacts that most legged robots operate under. While the assumption has slightly different interpretations across contact models, which are extremely well documented by [2], almost universally assume that impacts happens over a short time and that the other finite forces other than the contact force can be neglected. Although these assumptions greatly simplify our expressions for the dynamics between rigid bodies, it has been noted that contact models that operate under these assumptions perform poorly when compared with data gathered from actual collisions [3].

A possible explanation for why these rigid body contact models are poor predictors of actual impacts is that impacts do not occur instantaneously. This is supported by a preliminary result from testing with the Drake [4] time-stepping simulator. While tracking a walking trajectory on a planar five-link-biped, the impacts were observed to take a short but non-instantaneous amount of time (on the order of 4 - 10ms). In this time, the actuator torques as well as gravitational force have a non-negligible contribution to post-impact velocities. A non-instantaneous impact may have even greater implications on real robots, where collisions have been observed to occur on even longer timescales. In addition to uncertainty in impact duration, other relevant types of uncertainty likely include the well observed time of impact [5] and interface between the robot and its environment. I seek to quantify the dependence on those types of uncertainty and also reveal other sources of uncertainty such as impact angle or energy at touchdown that legged robots are sensitive to.

To identify the relevant contact model parameters for legged locomotion, I intend to gather data from executing jumping and walking trajectories both on hardware and in simulation. Walking is chosen for the relative ubiquity in expected tasks for legged robots, and jumping is chosen for the potential richness in impact data.

On hardware, experiments will be run using Cassie, a robot built by Agility Robotics with adequate sensors and control authority to be express and take advantage of a more complex contact model. In conjunction to collecting empirical data from Cassie, I will also evaluate contact data from different simulators with different contact models and parameters. The simulators will include but may not be limited to: Drake [4], Mujoco [6], and Gazebo. The aim of exploring different simulators is to isolate and quantify the implications of different simplifying assumptions about the contact model.

References

[1] S. Mason, N. Rotella, S. Schaal, and L. Righetti, "Balancing and walking using full dynamics lqr control with contact constraints," in *2016 IEEE-RAS 16th International Conference on Humanoid Robots (Humanoids)*. IEEE, 2016, pp. 63–68.

[2] A. Chatterjee, *Rigid body collisions: some general considerations, new collision laws, and some experimental data*. Cornell University Ithaca, NY, 1997.

[3] N. Fazeli, S. Zapolsky, E. Drumwright, and A. Rodriguez, "Learning data-efficient rigid-body contact models: Case study of planar impact," *arXiv preprint arXiv:1710.05947*, 2017.

[4] R. Tedrake *et al.*, "Drake: A planning, control, and analysis toolbox for nonlinear dynamical systems," 2014.

[5] G. Bledt, P. M. Wensing, S. Ingersoll, and S. Kim, "Contact model fusion for event-based locomotion in unstructured terrains," in *2018 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2018, pp. 1–8.

[6] E. Todorov, T. Erez, and Y. Tassa, "Mujoco: A physics engine for model-based control," in *2012 IEEE/RSJ International Conference on Intelligent Robots and Systems*. IEEE, 2012, pp. 5026–5033.