Model Hierarchy Predictive Control of Legged Locomotion

He Li
Department of Aerospace and Mechanical Engineering
University of Notre Dame
Notre Dame, IN 46556
Email: hli25@nd.edu

Patrick M. Wensing
Department of Aerospace and Mechanical Engineering
University of Notre Dame
Notre Dame, IN 46556
Email: pwensing@nd.edu

I. Background

Model Predictive Control (MPC) has been gaining popularity in the legged robotics community over the past decade, with great success demonstrated on several platforms, such as MIT Cheetah series robots, ANYmal, HPR-2, etc. Conventional MPC takes one of the two approaches, simple-model MPC or whole-body MPC. Simple-model MPC has the advantage of fast computation, but it separates the planning stage and the whole-body control stage. Balance constraints are often considered in the planning stage, and are not guaranteed in the control stage. On the other hand, whole-body MPC explores the full state space and control space, unlocking more complex motions while respecting stability constraints. However, the high computational burden has hindered its application for online use. In this work, we propose Model Hierarchy Predictive Control (MHPC), which unifies planning and control, and has comparable performance to whole-body MPC while significantly reducing the computational cost.

II. Methods

As opposed to simple-model MPC which solves a sequence of optimization problems, MHPC constructs a single optimization posed over a hierarchy of models. Figure 1(a) conceptually illustrates the main idea of MHPC using a planar quadruped that needs to account for gaps when planning its movement. In the current stance and next flight, the robot explores its full state and control space (coordinates its legs and body) to avoid the gap. Since the subsequent stance and flight are far away, reasoning about the whole-body dynamics could be a burden to the planning process. Instead, the robot ignores its leg dynamics, and simply takes plans its body movement. In this way, the quadruped focuses on its near-term balance while having a rough plan in mind for the long run. More formally speaking, MHPC formulates this jumping task as an optimization problem, where the whole-body dynamics and gap avoidance are imposed as constraints in the near term, and the rigid-body dynamics (of body) is imposed in the long term. The consistency between the two is enforced by a low-dimensional constraint. The reader is referred to [1] for the details of this approach.

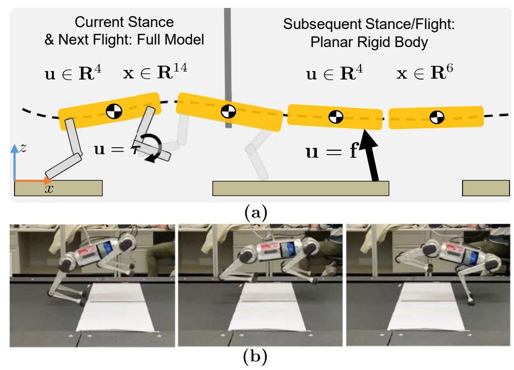

Fig. 1. (a) Illustration of MHPC for a quadruped jumping over a gap. (b) Hardware implementation of MHPC on MIT Mini Cheetah for gap jumping.

III. Results & Discussion

The proposed MHPC approach was studied in simulation in [1] with a quadruped to benchmark disturbance rejection performance and computational cost. We recap key results here due to the limited space. By assigning proper planning times for whole-body model and simple model, the MHPC could reject comparably large disturbances as whole-body MPC while reducing the computational cost by half. We anticipate this benefit will be more significant for higher-order systems and with C++ implementation. The MHPC was then implemented on MIT Mini Cheetah hardware to achieve bounding with a forward speed of 1.5 m/s while avoiding a gap. Figure 1(b) shows time-series snapshots of the hardware implementation. The control and state trajectories are generated offline and are executed online with an additional PD controller to gain more robustness. The success of hardware implementation validates the physical feasibility of the MHPC, and encourages us to move to its online implementation in future work.

IV. Acknowledgments

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References

[1] H. Li, R. J. Frei, and P. M. Wensing, "Model hierarchy predictive control of robotic systems," *IEEE Robotics and Automation Letters*, vol. 6, no. 2, pp. 3373–3380, 2021.