Robust Task and Motion Planning for Agile Locomotion In The Now

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1 Introduction

Contact-based decision and planning methods are becoming increasingly important to endow higher levels of autonomy for legged robots. Formal synthesis methods derived from symbolic systems have great potential for reasoning about high-level locomotion decisions and achieving complex maneuvering behaviors with correctness guarantees [1]. Our previous study constructed a set of dynamic locomotion models for legged robots to serve as a template library for handling diverse environmental events. We took a first step toward formally devising an architecture composed of task planning and control of whole-body dynamic locomotion behaviors in constrained and dynamically changing environments [2]. At the high level, we formulated a two-player temporal logic game between the multi-limb locomotion planner and its dynamic environment to synthesize a winning strategy that delivered symbolic locomotion actions, analogous to sequential composition [3]. These locomotion actions satisfied the desired high-level task specifications expressed in a fragment of linear temporal logic.

However, those actions may fail in generating feasible locomotion trajectories when being executed via a low-level motion planner. To address this problem, we recently construct a robust finite transition system that synthesizes a locomotion controller that fulfills state reachability constraints (see Fig. 1). Meanwhile, we devise a replanning strategy that takes into consideration sudden environmental changes or large state disturbances to increase the robustness of the resulting locomotion behaviors. We have achieved preliminary results on formally proving the correctness of the layered locomotion framework guaranteeing a robust implementation by the motion planning layer. Simulations of reactive locomotion behaviors in diverse environments indicate that our framework has the potential to serve as a theoretical foundation for robust and intelligent locomotion behaviors.

2 Main Contribution

The contributions of this study are in threefold: (i) devising symbolic reasoning methods that make decisions on keyframe states of the dynamic locomotion process in response to the dynamically changing environment; (ii) ensuring robust locomotion under bounded disturbances by reasoning about keyframe state reachability; (iii) employing game theory to compose complex locomotion behaviors sequentially.

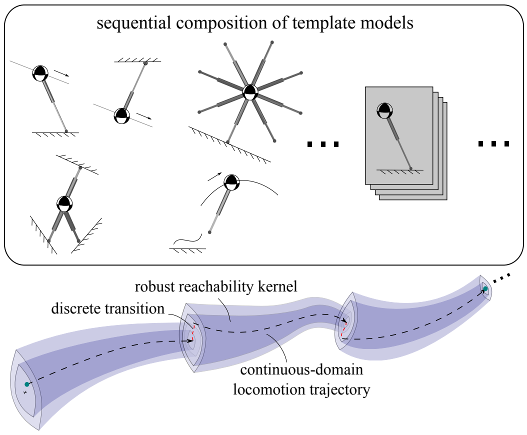

Figure 1: Illustration of template-based locomotion behaviors dynamically interacting with complex environments. Our study focuses on how to make model abstractions and high-level decisions for complex environments. A fundamental problem is how to use template models to characterize essential locomotion modes and sequentially compose these modes to achieve agile and robust locomotion.

3 Ongoing Works

Our current work focuses on the following: (i) Our task planner has a one-walking step horizon (i.e., planning *in the now*) and may sometimes result in myopic locomotion decisions. A natural alternative is to design a recovery strategy over the next multiple walking steps. An obvious downside of this strategy is the increasing complexity in designing recovery strategies. We should compromise the recovery strategy complexity and range of field of view when designing the planning horizon. (ii) To make the hierarchical planning approach applicable to locomotion tasks in more complex environments, we ought to relax environment assumptions and model more realistic scenes. For instance, how to formally design recovery strategies for slippery terrains, large tilting angles, and swing foot obstacle collision is a significant direction.

References

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[1]* Part of this work was collaborated with Yinan Li and Jun Liu from University of Waterloo, Luis Sentis and Ufuk Topcu from UT Austin.