Whole-body Dynamic Locomotion Planning and Control for a Hydraulic Humanoid Robot

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***Abstract*—We summarize recent efforts of our research group toward developing algorithms for generating whole-body dynamic walking gaits from observations of (possibly complex) terrain and stabilizing their execution on physical robots. Our approach is to break the planning problem into three subproblems that we solve in sequence, each stage exploiting solutions from the previous. We are actively evaluating these algorithms using a physical Atlas humanoid robot at MIT.**

Keywords: locomotion; optimization; model-based control; legged robots

I. Introduction

Achieving dynamically-stable locomotion over irregular terrain is a central goal of legged robotics. The problem of generating dynamic walking motions can be extraordinarily complex, involving combinatoric selection of footsteps and optimization of a kinodynamically-feasible trajectory for a high-dimensional, hybrid dynamical system. We tackle this problem by subdividing it into three stages: segmentation of the terrain into a sequence of convex safe regions, optimizing footsteps and centroidal dynamics trajectories through those regions, and finally optimizing the whole-body trajectory. Stable plan execution on the robot is achieved by efficiently solving convex quadratic programs (QP) in real time.

II. Summary of Approach

A. Terrain Segmentation and Assignment

To find candidate safe regions for footsteps, we expand sampled terrain points into convex regions that are safe for foot placement using the IRIS algorithm [1]. Terrain safety criteria include avoiding foot placements on steep or uneven terrain, as well as avoiding step locations which would bring the robot's upper body into collision with the environment.

Once safe regions have been generated, footsteps locations can be planned within those regions. We search over the number of steps to take, the leading foot to choose, and the assignment of each step to one of the safe regions. This can be formulated as a mixed-integer QP on a simplified model of the robot's kinematically-reachable steps or more generally as a graph search over the safe regions combined with a nonlinear optimization to find the footstep positions and orientations, both of which are efficiently solvable.

B. Centroidal Dynamics and Footstep Planning

Given the safe polygonal terrain regions and their nominal footstep assignments, we next simultaneously searching for contact (foot) positions within these regions, ground reaction forces, and the center of mass trajectory while ensuring dynamic feasibility. The centroidal angular momentum of the robot is minimized throughout the walking motion (although incorporating more general angular momentum behaviors would be straightforward). The resulting optimization takes the form of a nonlinear program (NLP) with linear constraints. By applying sequential quadratic programming to this problem, we can guarantee that the solution to each QP in the sequence is feasible, thus creating the opportunity for early termination if hard time constraints are present.

C. Whole-body Planning

The final step is to solve a NLP to optimize a whole-body plan that is consistent with the centroidal dynamics trajectory while incorporating kinematic constraints, such as end-effector positioning and collision avoidance.

D. Stabilization

The stabilization problem can be formulated as a convex QP by exploiting the fact that the instantaneous dynamics, contact, and input constraints can be expressed linearly. A key observation about this approach is that the set of active inequality constraints typically changes infrequently between consecutive control steps, permitting the use of efficient active-set solvers for real time control [2].

III. Results

We will describe our results in achieving stable execution of walking trajectories with a 34-DoF Atlas humanoid robot.

References

[1] Robin L.H. Deits and Russ Tedrake. Computing large convex regions of obstacle-free space through semidefinite programming. *Under Review*, August 2014.

[2] Scott Kuindersma, Frank Permenter, and Russ Tedrake. An efficiently solvable quadratic program for stabilizing dynamic locomotion. In *Proceedings of the International Conference on Robotics and Automation*, May 2014.