Feedback Control of Dynamic Bounding Gaits on LittleDog

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SUMMARY

An accurate planar model of LittleDog, a stiff quadrupedal robot, was developed and identified. Using the model, a control algorithm based on trajectory tracking Linear Quadratic Regulator was developed and implemented on the robot. Open-loop dynamic trajectories generated by hand as well as by motion-planning algorithms were then stabilized on the robot. The approach allows a wider range of dynamic motions of LittleDog, allowing it to navigate terrain more efficiently.

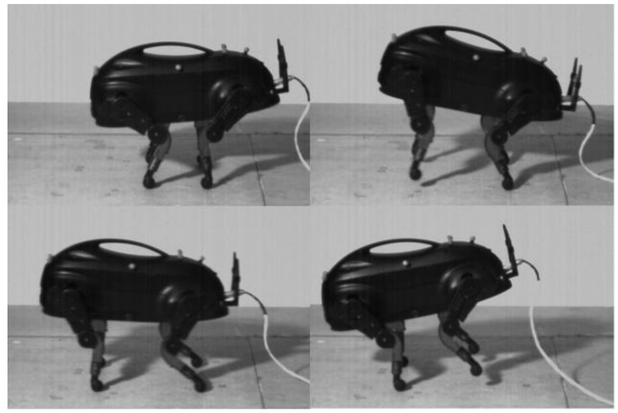
INTRODUCTION

LittleDog is a point-foot quadrupedal robot developed by Boston Dynamics for the DARPA Learning Locomotion program to study locomotion over very rough terrain. The mechanical design uses highly-geared DC motors, most suitable for position control. Previous work has demonstrated controllers capable of achieving statically stable or ZMP based walking gaits over rough terrain [e.g. 1]. In these cases, there are always at least three legs on the ground for a significant portion of the gait, allowing considerable control of the ground reaction forces. Dynamic motions requiring fewer than three feet on the ground allow for more agile and more rapid locomotion, but the control is complicated because traditional methods such as ZMP based control are ineffective when there is no support polygon.

Previous work has achieved repeatable short duration (less than 1 s) open-loop dynamic motions with the robot from a small set of initial starting poses [2]. We extend this work by developing the capability to execute continuous dynamic gaits without interruption. Unlike the short-duration motions, this requires feedback stabilization for the trajectories. As a benefit, feedback makes the behavior more robust to variations in terrain. In particular, we explore motion generation and feedback stabilization of a 'bounding' gait, in which the robot alternates between supporting itself with front and back feet.

METHODS

We developed an accurate planar model of LittleDog including its interaction with the ground, a necessary component for both feedback control and for motion planning algorithms. The robot was modeled as a rigid five-link planar body with a spring-damper ground contact with slipping. The dynamics of the body, motors and ground collisions were fit to observed behavior of the actual robot.



LittleDog performing a dynamic bounding motion

Open-loop bounding trajectories were generated by hand as well as with RRT-based motion-planning algorithms in simulation. The identified model was used to calculate linearized dynamics of the robot around the nominal dynamic bounding trajectory and control input. Finally, the trajectory was stabilized on the robot by applying an LTV controller based on the linearized dynamics.

RESULTS AND DISCUSSION

The performance and robustness of the feedback control policy was compared to that of the open-loop policy. The tests were done on flat terrain, inclined terrain, as well as on moderately rough terrain.

Dynamic motions greatly increase LittleDog's ability to navigate over terrain, particularly in cases where the navigation is impossible with static gaits. Feedback stabilization improves robustness and repeatability, but is challenging due to the difficulty in achieving an accurate model of the dynamics. The approach of stabilizing open-loop trajectories by trajectory stabilization with LQR is not specific to LittleDog and can be potentially useful for a wide variety of other robots.

REFERENCES

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