

Walking on Rough Terrain with a Position Controlled Quadruped

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Motivation

Walking on rough terrain represents a fundamental challenge in robotics. Position controlled robots can theoretically traverse the most diverse terrain, including severely discontinuous terrains as shown in Figure 1. At the same time, a position control robot can be very stiff, and difficult to control. The difficulty stems from the underactuated nature of the system: the robot can push against the ground, but cannot pull. Therefore, the system cannot execute arbitrary accelerations of its body without feet coming off the ground or slipping.

We approach the problem using the LittleDog quadruped robot platform developed by Boston Dynamics, Inc., for the DARPA funded Learning Locomotion program. The task is to develop a robust controller to enable traversal of rough terrain by the 12 Degree of Freedom robot (see Figure 2).



Figure 1: LittleDog robot, which can navigate intermittent terrains which require careful foot placements.

Controller

To simplify the problem, we restrict our gait to a static crawl. We found that such a gait can traverse surprisingly challenging terrain at moderate speeds. The robot first moves its body to some position where its center-of-mass (COM) is over the support polygon, and then moves a single foot, placing it in a desirable location. We developed a hierarchical controller to accomplish this task. At the highest level, a desired center of body trajectory is chosen by using value iteration. Between each step, a foot planner selects a foot to move, position to move the foot to, and pose for the body to attain. The foot planner randomly samples this 9-dimensional space from a probability distribution that favors certain empirically established choices. Each sample is assigned a score by a number of heuristic functions which attempt to approximate the long-term cost of selecting the sample. The primary heuristics used include deviation from a nominal gait pattern, and terrain costs are established to encourage picking foot positions that would minimize foot slippage. Kinematic infeasibility and predicted foot collisions are also penalized.

A lower level joint-spline generator picks joint trajectories to enable the robot to achieve the desired body pose and foot swing. This spline, generated between steps, is then executed by a PD controller at 1kHz on the robot. The joint splines are essentially open-loop trajectories that are executed to carry out a single step. However, various

forms of feedback are inserted in particular to allow for re-planning the step if anything goes wrong, for example if feet slipped while moving the body.

Results and Future Work

Ignoring computation time, we are able to traverse moderately rough terrain at 4cm / sec (see Figure 2). At slower speeds of 1.5cm/sec, the robot was able to traverse rough terrain it had never seen before (Figure 3) with a 100% success rate out of 7 trials. These results are encouraging, and indicate that the static crawl gait is surprisingly adept.



Figure 2: LittleDog walking on rough terrain

Machine learning techniques have been incorporated at various levels of the control framework, including fast collision detection [], path planning, and can be applied to tune the weights on the heuristic penalties in the foot planner. The hierarchical controller offers these advantages, but much there remains a lot of room for improvement using these techniques, and this is a primary goal of the DARPA Learning Locomotion program.

To realize our goals of walking quickly over very rough terrain, we must begin to move away from the pseudo-fully-actuated realm of static walking, and move to more dynamic gaits and maneuvers. Quadruped animals typically only use a static crawl when moving very slowly; a basic walk gait, at moderate speeds usually has a phase where only two legs are on the ground. New techniques will need to be developed to enable a quadruped robot to walk dynamically, and to understand how to continue walking stably over time when we have very limited actuation capabilities, as is the case when fewer than 3 feet are on the ground at one time.

References

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