Deadbeat Control on the ATRIAS Robot

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1 Motivation

Theoretical models of running suggest that this gait is deadbeat stable in the presence of large ground height disturbance [1, 2]. The evaluation of this theory on legged robot platforms should enable more robust and agile behavior of these machines and help to pinpoint gaps in the current understanding of the control of legged locomotion. Despite the benefit of this interaction between theory and experiment, implementations and evaluations of the deadbeat-control strategies on robot platforms have largely remained pending. We attempt to close this gap (Fig. 1).

2 Our Approach

We use ATRIAS as the legged robot platform for testing the theory. ATRIAS is a human-size biped originally developed by the Dynamic Robotics Laboratory at Oregon State University [3]. The robot mimics the mass distribution of the spring mass model which underlies the deadbeat control theory. ATRIAS is capable of locomotion in 3-D or on the boom. We implement the theoretical model in a stepwise fashion, focusing on boom locomotion first and then generalizing to 3-D.

For the implementation of the theoretical model, we use control mapping techniques [4] (Fig. 2). If the robot's center of mass tracks the spring mass model's point mass behavior, then applying the leg placement control derived from the model on the hardware should result in deadbeat gait behavior. To achieve the stance phase tracking, we rely on LQR techniques that treat the ground reaction forces as control inputs and track the spring mass reference behavior while stabilizing the angular momentum of the ATRIAS robot not captured in the underlying theory. For replicating the leg placement of the model in the robot, we convert the model's landing condition into a joint trajectory, which is then tracked with computed torque control.

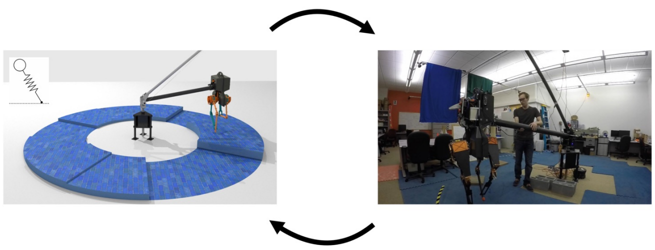

Figure 1: Evaluation of deadbeat control predicted by the theory of running gaits in bipedal robot experiments.

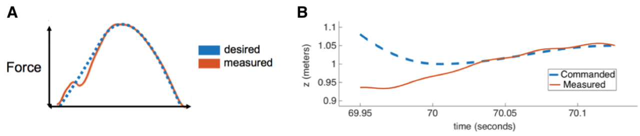

Figure 2: Tracking the stance behavior and the swing leg placement of the underlying spring mass model in the ATRIAS robot.

3 Current Results

We currently achieve good tracking of the desired stance and swing behavior in detailed simulations of ATRIAS; however, hardware experiments highlight mechanical limitations of the machine that need to be overcome before the deadbeat control theory can be tested on uneven ground. In both simulation and hardware, we track the target foot position within the mechanical oscillation limits of the robot legs ($\pm$5 mm at 20 Hz). In stance, we stabilize ATRIAS's position and orientation about the desired spring-mass model trajectories, although in hardware, the tracking is not yet accurate enough to perform the single-legged balance that the simulation achieves. In addition, for both simulation and hardware, we find that the ground reaction forces applied in stance deviate from the assumed simplified model due to collisions and error correction. To compensate for this deviation, we add adaptive control techniques improving the gait tracking as more and more steps are taken by the robot.

Although the implemented control mapping techniques track the spring mass model's swing and stance behavior, we found that the lateral control loop was infeasible on hardware as ATRIASs knees bend laterally and break under the loading conditions required for running.

4 Future Work

We are systematically designing a control that can map the behavior of the simplified spring mass model onto the ATRIAS robot platform. As we iterate this process, we plan to realize robust running over rough terrain in natural 3-D environments. In the short term, we will focus on overcoming the lateral breaking of the robot knees either by parameterizing our kinematics model with the loading condition or by ignoring lateral perturbations in stance. Over the longer term, we expect to evaluate the deadbeat control predicted by the theoretical running models in running experiments with ATRIAS on uneven ground. We believe that systematically iterating between deriving controls from basic theory and applying them to physical robots will result in improved understanding of fundamental principles as well as in robot performance that extends the state of the art and agrees with conceptual expectations.

5 Acknowledgment

This work is supported in part by the US National Science Foundation (CMMI-1100232 and CPS-1239143) and the DARPA M3 program (W91CRB-11-1-0002).

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